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# SUBMITAL TO USCG
# FOR
# ALTERNATE MANAGEMENT SYSTEM REVIEW

# OF

# THE VENTURI OXYGEN STRIPPING (VOS) BALLAST WATER MANAGEMENT SYSTEM

Date: June, 2013

# Table of Contents

# Introduction

This submittal to the United States Coast Guard is for the approval of N.E.I. Treatment Systems' Venturi Oxygen Stripping (VOS) Ballast Water Management System (BWMS) as an Alternate Management System (AMS). N.E.I. is submitting for AMS status as described in 33 CFR Part 151, 46 CFR Part 162. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters. N.E.I. is requesting review and approval for VOS systems capable of treating a range of ballast capacities from 100 $m^3$/hr – 6,800 $m^3$/hr. for all types of water. N.E.I. has completed extensive testing through the Maritime Environmental Resource Center under Dr. Mario Tamburri. This testing included; lab scale, land-based, fresh water and shipboard trials. N.E.I. has completed production installations on a wide range of vessels, and has included that information in the appendices.

Information included in this submittal is in accordance with paragraph 151.2028 of the CFR reference describing information required by a BWMS to be considered for AMS status.

Existing Flag Approvals from:

1. Liberia
2. Malta
3. Marshall Islands
4. The Netherlands
5. Panama

Testing Laboratory contact information for:

- Maritime Environmental Resource Center (MERC)/Chesapeake Biological Laboratory (CBL)
- Retlif Testing Laboratories
- BMT Fleet Technology Ltd

The testing described in this document includes:

- Pilot scale and production scale land-based Testing
- Shipboard Testing of production unit
- Fresh Water Testing-Lake Lariet Maryland
- Brackish Water Testing
- Salt Water Testing
- Environmental Testing
- Corrosion Testing
- Coating Testing

# Flag Approval

Before a BWMS can be considered for USCG AMS status, the BWMS must have received foreign Type Approval as an IMO BWMS from a Flag Administration.

The 2004 IMO Convention on Ballast Water and Sediments requires the Flag of a vessel to issue a Type Approval Certificate, or specific acceptance of another Type Approval Certificate, directly to a BWMS. N.E.I has sold, installed and commissioned VOS systems to over two dozen vessels flying five different Flags. N.E.I. has submitted VOS for Type Approval to each of the customer Flags, and was granted all approvals with no restrictions (please see *Appendix-A* for certificates). In addition to direct review by the administration, Liberia contracted with ABS to complete a full technical review of all data for accuracy and relevance. This full report is included within Appendix-A, as it is the foundation for all five N.E.I. Flag Approvals.

In addition to ABS, The Netherlands contracted the Independent MArine biology RESearch institute; IMARES, to review and advise on the Type Approval of VOS (using the ABS review as the submission for Type Approval), the Netherlands issued full approval with no restrictions.

The Type Approval Certificates on pages 7 – 11 below are images of the Flag Approvals from; Liberia, Malta, Marshall Islands, The Netherlands and Panama.

No 02NEI092211

# THE REPUBLIC OF LIBERIA

**BUREAU OF MARITIME AFFAIRS**

## TYPE APPROVAL CERTIFICATE OF BALLAST WATER MANAGEMENT SYSTEM

This is to certify that the Ballast Water Management System listed below has been examined and tested in accordance with the requirements of the specifications contained in the Guidelines contained in IMO resolution MEPC.174 (58). This certificate is valid only for the Ballast Water Management System referred to below.

Ballast Water Management System supplied by or under license from NEI Treatment Systems, LLC

Under type and model designation VOS-500 to VOS 6500 and incorporating:

Ballast Water Management System manufactured by or under license from NEI Treatment Systems, LLC

To equipment/assembly drawing No: VOS 500 to VOS 6000 Date: 8 December 2010

Other equipment manufactured by: N/A

To equipment/assembly drawing No.: N/A Date: N/A

Treatment Rated Capacity: 100 - 6,500 m3/h

A copy of this Type Approval Certificate should be carried on board a vessel fitted with this Ballast Water Management System at all times. A reference to the test protocol and a copy of the test results should be available for inspection on board the vessel.

Signed ........ M Ansumana ........

Margaret Ansumana

Deputy Commissioner of Maritime Affairs,

Republic of Liberia

Dated this 22nd day of September 2011

BALLAST WATER MANAGEMENT SYSTEM

TYPE APPROVAL COMPLIANCE CERTIFICATE

This is to certify that the Ballast Water Management System listed below was examined and tested in accordance with the requirements of the specifications contained in the Guidelines contained in IMO Resolution MEPC.174 (58). This Type Approval Compliance Certificate is valid only for the Ballast Water Management System referred to below.

| | | | |
|---|---|---|---|
| *Ballast Water Management System supplied by or under licence from:* | NEI Treatment Systems, LLC | | |
| *Under type and model designation* | VOS-2500 | | |
| *and incorporating:* | | | |
| *Ballast Water Management System manufactured by or under licence from:* | NEI Treatment Systems, LLC | | |
| *To equipment/assembly drawing No.:* | 07-2500-101 | *Date:* | 29 August 2007 |
| *Other equipment manufactured by:* | -- | | |
| *To equipment/assembly drawing No.:* | -- | *Date:* | -- |
| *Treatment Rated Capacity:* | 2,500 $m^3$/h | | |

A copy of this Type Approval Compliance Certificate should be carried on board a vessel fitted with this Ballast Water Management System at all times. A reference to the test protocol and a copy of the test results should be available for inspection on board the vessel.

No Limiting Conditions imposed.

This Type Approval Compliance Certificate is based on the Type Approval Certificate No. 02 NEI 070809 issued by the Republic of Liberia on 8 July 2009.

**Issued** at Valletta Malta this **19 January 2010**

L C Vassallo
*Registrar-General of*
*Shipping and Seamen*

**REPUBLIC OF THE MARSHALL ISLANDS**

**Office of the Maritime Administrator**

## TYPE APPROVAL CERTIFICATE OF BALLAST WATER MANAGEMENT SYSTEM

This is to certify that the Ballast Water Management System listed below has been examined and tested in accordance with the requirements of the specifications contained in the Guidelines contained in IMO resolution MEPC.174(58). This certificate is valid only for the Ballast Water Management System referred to below.

Ballast Water Management System supplied by or under license from NEI Treatment Systems, LLC

Under type and model designation VOS-500 TO VOS-6000 and incorporating:

Ballast Water Management System manufactured by or under license from NEI Treatment Systems, LLC

To equipment/assembly drawing No.: VOS-500 TO VOS-6000 Date: 8 December 2010

Other equipment manufactured by: N/A

To equipment/assembly drawing No.: N/A Date:

Treatment Rated Capacity: 100 - 6,500 $m^3/h$

A copy of this Type Approval Certificate should be carried on board a vessel fitted with this Ballast Water Management System at all times. A reference to the test protocol and a copy of the test results should be available for inspection on board the vessel.

No limiting conditions applied.

Dated this 6th of August, 2011.

Signed

Deputy Commissioner of Maritime Affairs
Republic of the Marshall Islands

[seal]

The Netherlands

## TYPE APPROVAL CERTIFICATE OF BALLAST WATER MANAGEMENT SYSTEM

This is to certify that the ballast water management system listed below has been examined and tested in accordance with the requirements of the specifications contained in the Guidelines contained in IMO resolution MEPC.174(58). This certificate is valid only for the ballast water management system referred to below.

Ballast water management system supplied by **NEI Treatment Systems, LLC**

Under type and model designation **VOS-500 to VOS-6000** and incorporating:

Ballast water management system manufactured by or under license from **NEI Treatment Systems, LLC**

to equipment/assembly drawing **VOS-500 to VOS-6000** Date: **April 2011**

Other equipment manufactured by **N/A**

to equipment/assembly drawing No. **N/A**

Treatment rated capacity **100 – 6,500** m3/h

A copy of this Type Approval Certificate, should be carried on board a vessel fitted with this ballast water management system at all times. A reference to the test protocol and a copy of the test results should be available for inspection on board the vessel.

Issued at Rotterdam, **18 July 2011**, under no. **6698/2011**

This certificate remains valid, provided no alternations or modifications are made, until 18 July 2016

**The Inspector general Transport and Water Management Inspectorate,**
on his behalf,
The Unitmanager Certificates and Permits

N Hutten Mansfeld,

Enc. Copy of the original test results.

Inspectorate for Transport, Public Works and Water Management
Public Works and Water Management Netherlands Government of the Netherlands Ministry of Transport

No.TA-0001

# THE REPUBLIC OF PANAMA
# PANAMA MARITIME AUTHORITY

## TYPE APPROVAL CERTIFICATE OF BALLAST WATER MANAGEMENT SYSTEM

This is to certify that the Ballast Water Management System listed below has been examined and tested in accordance with the requirements of the specifications contained in the Guidelines contained in the IMO resolution MEPC. 174(58). This certificate is valid only for the Ballast Water Management System referred below.

Ballast Water Management System supplied by or under license from NEI Treatment Systems, LLC.

Under type and model designation VOS-2500 and incorporation:

Ballast Water Management System manufactured by or under license from NEI Treatment Systems, LLC.

To equipment/ assembly drawing No: 07-2500-101 date: 29 of August 2007

Other equipment manufactured by: N/A

To equipment/ assembly drawing No: N/A date: N/A

Treatment Rated Capacity: 2,500 m3/h

A copy of this Type Approval Certificate should be carried on board vessels fitted with the Ballast Water Management System at all times. A reference to the test protocol and a copy of the test results should be available for inspection on board the vessel.

Signed ____________________

Director of Merchant Marine, Panama Maritime Authority

Dated this 11 day of February 2010.

RESOLUCIONES Y CONSULTAS

PM2:02 12 FEB '10

# Contact Information For VOS Test Team

**GENERAL TESTING INFORMATION**

VOS has been thoroughly tested under three disciplines; Biological, Environmental and Corrosion. All test results and descriptions are included as Appendix A – K to this document.

**BIOLOGICAL TESTING**

Biological Testing was completed by a team at the Maritime Environmental Resource Center (MERC). In addition to MERC, the team included the Smithsonian Environmental Resource Center (SERC), is the world's most experienced shipboard ballast sampling and testing group (please see *Appendix-B* for full MERC report)

Funding for much of the VOS testing came from grants issued by the Federal Ballast Water Technology Demonstration Program. Four applications to the program were submitted, over a span of four years. One application followed the next as phases of testing were successfully completed; pilot-scale, land-based testing, and eventually shipboard testing. All were successfully completed, and documented thoroughly (*please see Appendices C, D, E, G, H, I , J & K* for data and descriptions)

The Federal Ballast Water Technology Demonstration Program was a competitive grant, managed by NOAA with Application review and assistance from; USCG, MARAD, EPA, U.S. Fish and Wildlife and The U.S. Navy. The stated mission of the grant was:

***"Development, demonstration and, ultimately, use of effective treatment technologies on ships"***

The funding for testing VOS has achieved the stated mission of this Federal Grant program. More than 50 systems were funded; VOS is the only ballast water treatment system which is now successfully installed aboard a complete range of commercial vessels. N.E.I. has completed VOS installations ranging from 7,700DWT to over 320,00DWT (please see *Appendix-G* for ABS analysis). These installations include; Tankers, Bulkers and Container Ships.

The team which led the Biological testing is now one of the only laboratories approved as an Independent Laboratory (IL) under the Federal ballast water legislation; the Maritime Environmental Resource Center under Dr. Mario Tamburri.

**ENVIRONMENTAL TESTING**

In June 2012 the USCG rules for ballast water were published, they required Environmental Testing of electrical and control components. The required test criteria differ from the IMO specifications. It is because of this difference that N.E.I. contracted directly with The Retlif Testing Laboratories in New York, with a notice to the USCG prior to testing. At the time Retlif, was the only IL approved by the USCG and NSF to complete this work. In March 2013 nine days were spent testing to all of the criteria described in CFR; 162.060-30 *"Testing requirements for ballast water management systems (BWMS) components".* All required tests were completed with zero failures. Each test was managed and signed-off by the Retlif Engineer in charge. Please see *Appendix-D* for full Retlif Laboratory report.

**CORROSION AND COATING TESTING**

N.E.I has understood from the inception of VOS that corrosion protection was almost as large a commercial attribute as its ballast water treatment capabilities. Prior to VOS, vessels had employed ballast tank inerting purely for the benefits associated with inhibiting corrosion. Before the IMO finalizes corrosion testing requirements (which are in process) N.E.I. completed extensive long term testing of the effects and benefits of VOS on bare steel and coatings. Corrosion testing was the third pillar of the N.E.I. business plan: the **Biological Testing** proved VOS is a 100% effective ballast treatment system, the **Shipboard Testing AND Environmental Testing** proved the suitability of marine installation, the **Corrosion Testing** proved VOS brings a significant financial and safety element to the owner/operator of a vessel (*please see Appendices-E & F for full reports*)

For IMO Flag Type Approval a consideration of corrosion is expected but not yet formalized/required. The coating and corrosion tests completed on the VOS system proved VOS to be one of the few if not the only BWMS which will bring a significant reduction in bare steel corrosion (~85% in many areas) and reduction in creep where coatings are damaged. Additionally, contrary to all oxidizing BWMS, VOS will not put oxidizing stress on the coatings or steel of a vessel at any time.

BMT Fleet Technologies completed extensive corrosion testing over a period of 270 days. Though there is no formal test criterion for BWMS corrosion testing, the format of the VOS testing will be close, and over a longer term than what the IMO will require in the future.

**CONTACT INFORMATION BIOLOGICAL TESTING (pilot scale, land-based and shipboard)**

Dr. Mario Tamburri. Director

Maritime Environmental Resource Center
Chesapeake Biological Laboratory

One Williams Street
Solomons, MD 20688, USA

TEL: 1-410 326 7385

**CONTACT INFORMATION ENVIRONMENTAL TESTING**

Mr. Michael Bozza. Quality Assurance Manager
Mr. V. Rondon. Lead Environmental Test Engineer

Retlif Testing Laboratories
795 Marconi Avenue,
Ronkonkoma, NY 11779

TEL: 631-737-1500

**CONTACT INFORMATION CORROSION AND COATING TESTING**

Dr. Sanjay Tiku. Principal Materials Specialist

BMT FLEET TECHNOLOGY LIMITED
311 Legget Drive
Kanata, ON K2K 1Z8
Canada

# Biological Testing

As noted above the biological testing of VOS was completed using funding primarily from four grant awards, from a competitive Federal grant; The Ballast Water Technology Demonstration Program. Each grant was reviewed and awarded by NOAA with input from a panel that included; USCG, MARAD, EPA, US Fish and Wildlife and US Navy.

Testing was led by Dr. Mario Tamburri at the Maritime Environmental Resource Center. Dr. Tamburri is now Director of the Maritime Environmental Resource Center which is the first approved IL for USCG biological testing of a BWMS (*please see appendices B, C & J for full reports and raw data*).

## OVERVIEW OF THE VENTURI OXYGEN STRIPPING (VOS) BWMS

Venturi Oxygen Stripping (VOS) achieves full treatment by:

- Removing dissolved oxygen (DO) from influent ballast water during ballasting
- Maintaining the ballast tank environment in a low oxygen condition.
- VOS main component, the Stripping Gas Generator (SGG), is already used aboard tankers. The SGG is a modified Inert Gas Generator system, which is well understood by crews, SOLAS and class societies around the world.
- VOS is completely effective without the use of Active Substances. VOS is effective in all water types including but not limited to salt, brackish, fresh, polluted and muddy.

### Biology and Deoxygenation

At standard pressure and temperature the normal equilibrium concentration of molecular oxygen ($O_2$) dissolved from the air into natural water is approximately 7.0-8.0 milligrams per liter (mg/l). Aerobic aquatic life is sustained by this small amount of Dissolved Oxygen. There are areas of the world where D.O. is significantly below normal. These areas are known as “dead zones”. A dead zone results when organisms consume oxygen so rapidly that the D.O. concentration falls below approximately 1.0 mg/l. This condition is also known as hypoxic (hypoxia).

### VOS Generates Hypoxic Conditions

In a closed system, it is possible to physically induce hypoxia by exposing natural water to a low-oxygen gas. If a gas with a very low oxygen concentration is introduced to natural water, the gas and liquid oxygen concentrations are no longer in equilibrium. This physical imbalance causes oxygen to diffuse out of the water and into the gas until a new low-oxygen-equilibrium is achieved. In a closed system, such as a ship’s ballast system, oxygen will diffuse out of the aqueous phase into the gaseous phase, the gas bubbles simply vent to atmosphere, leaving low oxygen water in the tank.

**NOTE:** The oxygen being removed (stripped) is gaseous Dissolved Oxygen, not the liquid molecular oxygen of $H_2O$.

Using the Henry's Law constant for oxygen, it is a simple matter to calculate the required gas volume and gaseous oxygen concentration to establish a DO concentration below 1.0 mg/l. This is a physical process, and therefore is predictable and demonstrable. Because VOS leverages Henry's Law for treatment, the physical process is not impacted by water chemistry, suspended particulate matter, dissolved organic matter, salinity, turbidity or biological load. The new equilibrium will always be established. Ballast treatment based on deoxygenation has been repeatedly proven effective and reliable-regardless of water conditions.

**VOS Does Not Create Anoxic Conditions**

Henry's Law also ensures not all DO is removed from the ballast water. By introducing a limited volume of gas with low oxygen, Henry's Law dictates that a new low-oxygen-equilibrium is established. The water cannot completely deoxygenate. This is important; the total absence of DO in water is called anoxia. Anoxic conditions can lead to growth of sulfur-reducing and other anaerobic bacteria which can cause accelerated rates of steel corrosion.

Even a small amount of oxygen is toxic to anaerobic organisms. The presence of greater than 0.1 mg/l of D.O. ensures these bacteria stay dormant (if they are present at all). The VOS system cannot (because of Henry's Law), lower the DO concentration to levels capable of support anaerobic life, thus creating a hypoxic, not anoxic condition.

**Bubbles Enhance Deoxygenation**

Henry's Law establishes the DO concentration to gaseous oxygen concentration ratio. Henry's Law does not address dynamic conditions or the time required for a gas water mixture to reach a new oxygen equilibrium. The rate of deoxygenation is proportional to the total surface area between gas and water. This is a critical aspect of the VOS treatment, and what makes it unique in the BWTS market. After simply introducing a low-oxygen gas into the head space (ullage space), in a closed tank of water, it can take many days or weeks to deoxygenate properly. This is physical constant; the rate of de-oxygenation is proportional (and therefore wholly dependent upon) to the total surface area (exposure).

In natural water, if the transition from normal oxygen (normoxic) to hypoxic condition is slow, some organisms can change their metabolism to adjust to the low-oxygen condition. This is regular adaptation. There are organisms that can form cysts in approximately 24-hours, and "facultative" bacteria that can adjust to a variety of conditions. Therefore, a deoxygenation system designed to induce hypoxia very quickly is many times more effective in killing aquatic organisms, than a system which de-oxygenates the water slowly.

One proven method to significantly increase the deoxygenation rate in a closed system is to <u>increase</u> the total contact surface between gas and water - bubbles. For a given volume of gas water mixture, the surface-area-to-volume ratio is *maximized* when the size of individual bubbles is *minimized*. Smaller bubbles result in a much higher total contact surface area, and increase the deoxygenation rate. This proven method to increase the deoxygenation rate is accomplished within the N.E.I. Venturi Injectors.

**Two principles govern the development of this method to rapidly deoxygenate water:**

1. A mechanism to maximize the total surface area between low-oxygen-gas and water.
2. A source of sufficient low oxygen gas.

**Two VOS components provide these conditions:**

1. Total surface area is maximized by using **Venturi Injectors** to mix ballast water and stripping gas.
2. The source of low oxygen stripping gas is an Inert Gas Generator (IGG) with a modified “blue flame burner”, the unit is called a **Stripping Gas Generator (SGG).** IGG’s have been used aboard tankers as safety devices since the 1970’s, and are very well understood by crews, Class and SOLAS.

## <u>Treatment Description and Component Arrangements</u>

The Venturi Oxygen Stripping ballast water treatment system is a two-step process. The VOS system ensures both steps are followed.

### Inert Gas Generation

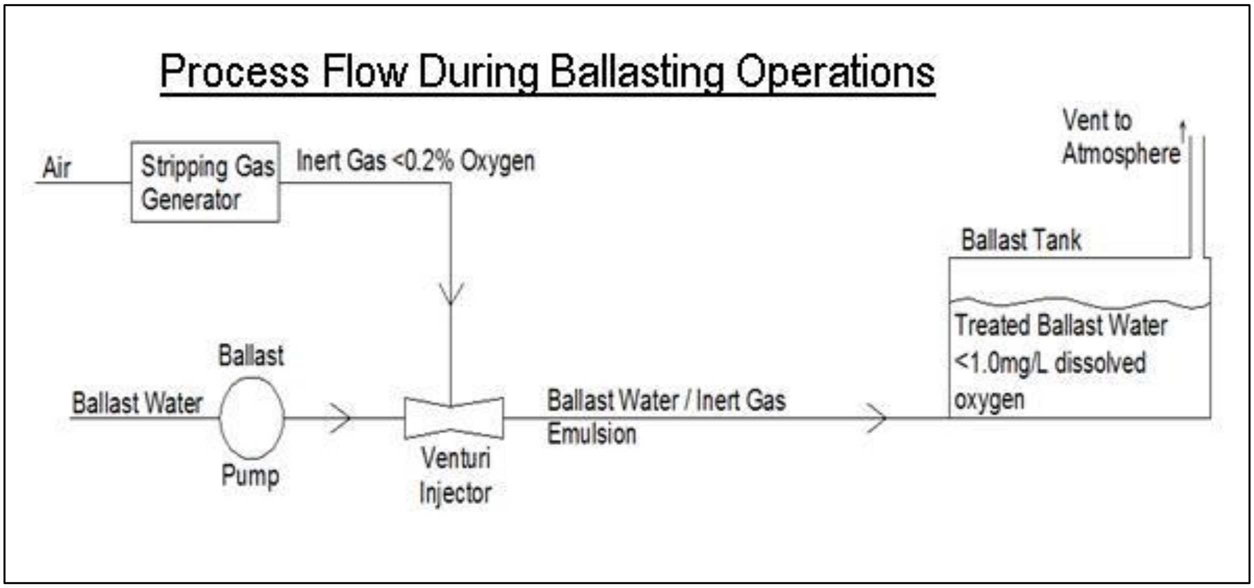
VOS treatment is achieved by mixing a very-low-oxygen gas, or “stripping” gas into the ballast water as it is pumped into the ballast tanks. Ballast tanks are maintained as low oxygen environments by filling them with inert gas during discharge.

- VOS generates and monitors the required low oxygen gas in a Stripping Gas Generator (SGG). N.E.I. refers to the low oxygen gas as: Stripping Gas when it is used to strip DO from ballast water, and
- Inert gas when it is used to fill the ballast tanks during ballast discharge.

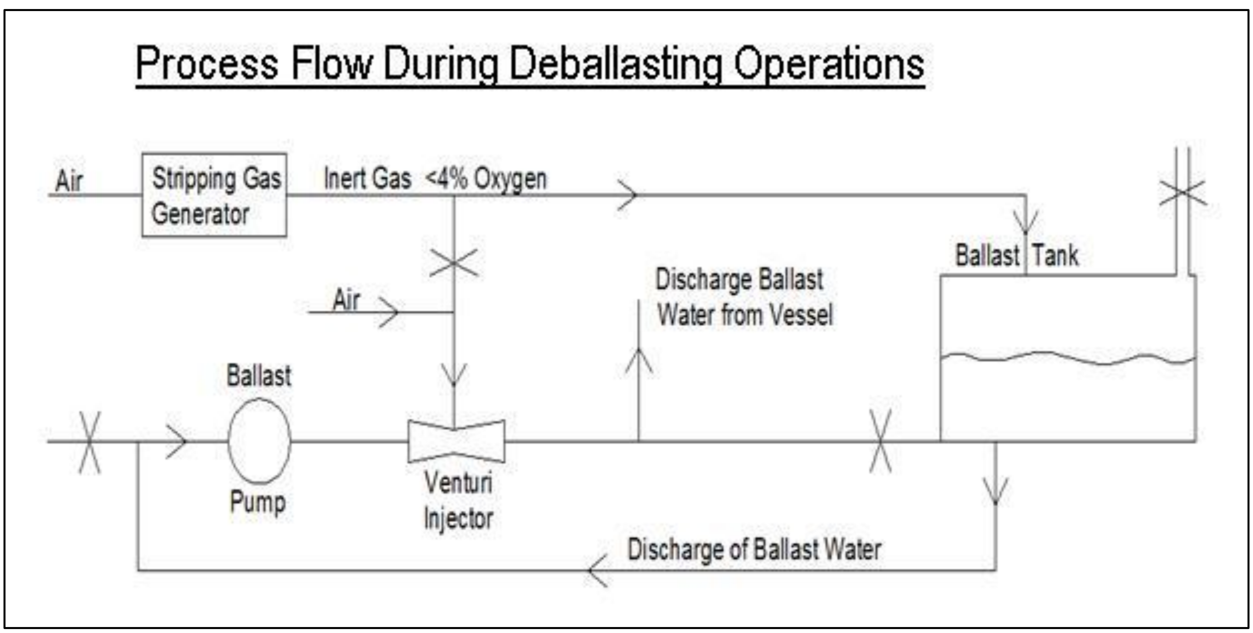
The SGG operates on the same principle as an Inert Gas Generator (IGG) on tankers. Tankers use IGG’s to generate inert gas to blanket cargo tanks, preventing explosions from flammable cargos. The very-low-oxygen gas, is generated by burning low sulfur marine diesel or gas oil, MDO or MGO (<1.5% sulfur). The gas consists mostly of nitrogen and carbon dioxide, it also includes small amounts of; oxygen, carbon monoxide and water.

**VOS, A Two Step Process:**

**STEP 1 Ballast Water Treatment**. Treatment occurs whenever ballast is taken into the ship, FIGURE 1:




**STEP 2 Ballast Tank Inerting**; Inerting occurs when ballast tanks are being discharged, FIGURE 2:




Step 1 and Step 2 require the SGG to be operating, to ensure adequate treatment of ballast water. Both steps ensure the water is suitable for discharge under the IMO Ballast Water Convention D-2 and USCG discharge standards.

**Step 1 Ballasting-VOS Treatment**

Step 1 of the VOS treatment occurs during ballasting only (intake), see Figure 1 above. When ballast water is pumped into the vessel, it is passed through a Venturi Injector (VI), which is installed downstream of the ballast pump(s).

The VIs creates cavitation and therefore a significant vacuum at the VI eductor port. This vacuum draws the VOS generated stripping gas into the ballast water stream. This step creates a mixing, cavitating and shearing environment. Immediately downstream of the eductor port, intense mixing of the gas and water creates a micro-fine bubble emulsion. The stripping gas being mixed into the water contains very low oxygen, this introduction of a low oxygen gas results in Dissolved Oxygen diffusing out of the ballast water and into the gas bubbles.

Natural DO content is related to water temperature. The VOS SGG produces 1.25x the volume of stripping gas to ballast water flow. This additional volume of gas ensures the VOS system can treat 100% of the world's oceans, rivers and lakes without consideration for salinity, temperature or turbidity.

Less than ten seconds after mixing in the VI and piping system, the stripping gas bubbles have fully deoxygenated the water. Again, the water type does not impact the VOS treatment in any way; fresh or salt, hot or cold, dirty or clean Henry's Law ensures the diffusion of DO from ballast water to stripping gas bubble will always occur. This physical process (constant) will establish a new oxygen equilibrium between DO in the water and gaseous oxygen concentration-resulting in a hypoxic environment deadly to organisms.

As the ballast tanks fill with VOS treated water, the stripping gas bubbles simply rise to the surface and vent to atmosphere through the VOS ventilation system.

The venting stripping gas creates a low-oxygen atmosphere (inert) in the ballast tank head (ullage) space. The magnetic vent check valves fitted to each ballast tank vent riser are "normally closed" units. The magnetically closed vents ensure fresh air does not enter the tanks in a volume sufficient to re-oxygenate the water. The VOS Magnetic Vent Check Valves also provide proper tank over pressure protection. As with normal ballast tank vents, they allow a full flow of ballast water if the tank is pressed or overfilled but also close to isolate the tank from fresh air.

VOS creates and maintains low DO in the ballast water, this quickly kills any oxygen dependent organism; in most cases within very few minutes or hours.

Phytoplankton can take longer to die. In the ballast tanks there is no light so Phytoplankton's normal light based respiration cannot continue. In addition there is not enough DO for the phytoplankton to revert to oxygen based respiration. The phytoplankton is also stressed by the small but very sudden pH change caused by VOS.

The regulated bacteria (for the IMO D-2 and USCG standards) cannot withstand the loss of DO combined with the slight, but sudden pH change. Like the Zooplankton the regulated bacteria die very quickly.

As well as the pure effects of deoxygenation, all of the VOS treated ballast water has been pumped through the venturi injectors. The eductor nozzle in the middle of the venturi injector is an intensely violent environment. There are very strong shearing and cavitation forces as bubbles form and collapse. These cavitation forces shear the cell walls of organisms as well as create the micro-fine bubble emulsion required for treatment. This extreme cavitation contributes to the effectiveness of the VOS treatment.

**Step 2: Deballasting/Ballast Tank Inerting**

Step 2 of VOS happens during ballast discharge, see FIGURE 2. Ballast is discharged and the ballast tanks are filled with inert gas.

During ballast discharge the SGG provides inert gas to the ullage space in the ballast tanks through the deck gas line. The deck gas line is connected to every ballast tank, generally through one vent riser on each ballast tank. Like cargo inerting systems, the SGG produces 125% the volume of inert gas to ballast flow, excess IG is vented to atmosphere through the P/V valve.

Ballast tanks are inerted to ensure the next load of treated ballast cannot re-aerate in the ballast tanks. Inerting also maintains the corrosion and coating protection VOS brings to the vessel. IG used for inerting may have a higher oxygen concentration than the stripping gas (Step 1) but not more than 4%.

The VOS SGG produces and ultra “clean” gas with an oxygen level of $1/10^{th}$ of 1%. This IG is 30-40 times lower in oxygen content than a typical IGG can produce. For the tanker community inerting the ballast environment provides an extra level of explosion proofing for the vessel. In a normal ballast tank environment, hydrocarbons from cargo or other sources can leak in to the ballast environment, creating an explosion hazard. It is for this reason that hydrocarbon sensors are installed in ballast tanks. When VOS is used, this threat is eliminated by the extremely low oxygen content. Again, this is 30-40 times lower than a typical IGG can produce (this is fully supported and acknowledged by SOLAS). **For full installation analysis please see Appendix –G for ABS review.**

**VOS does not require any retreatment:** In 2013 the GESAMP Committee of the IMO stated fully deoxygenated water does not require re-aeration upon discharge. This was based on the immediate dilution of ballast discharged from a sea-chest and the fact deoxygenated water will naturally re-aerate (Henry’s Law).

If an owner does not wish to discharge low DO water VOS provides two opportunities to re-aerate during discharge:

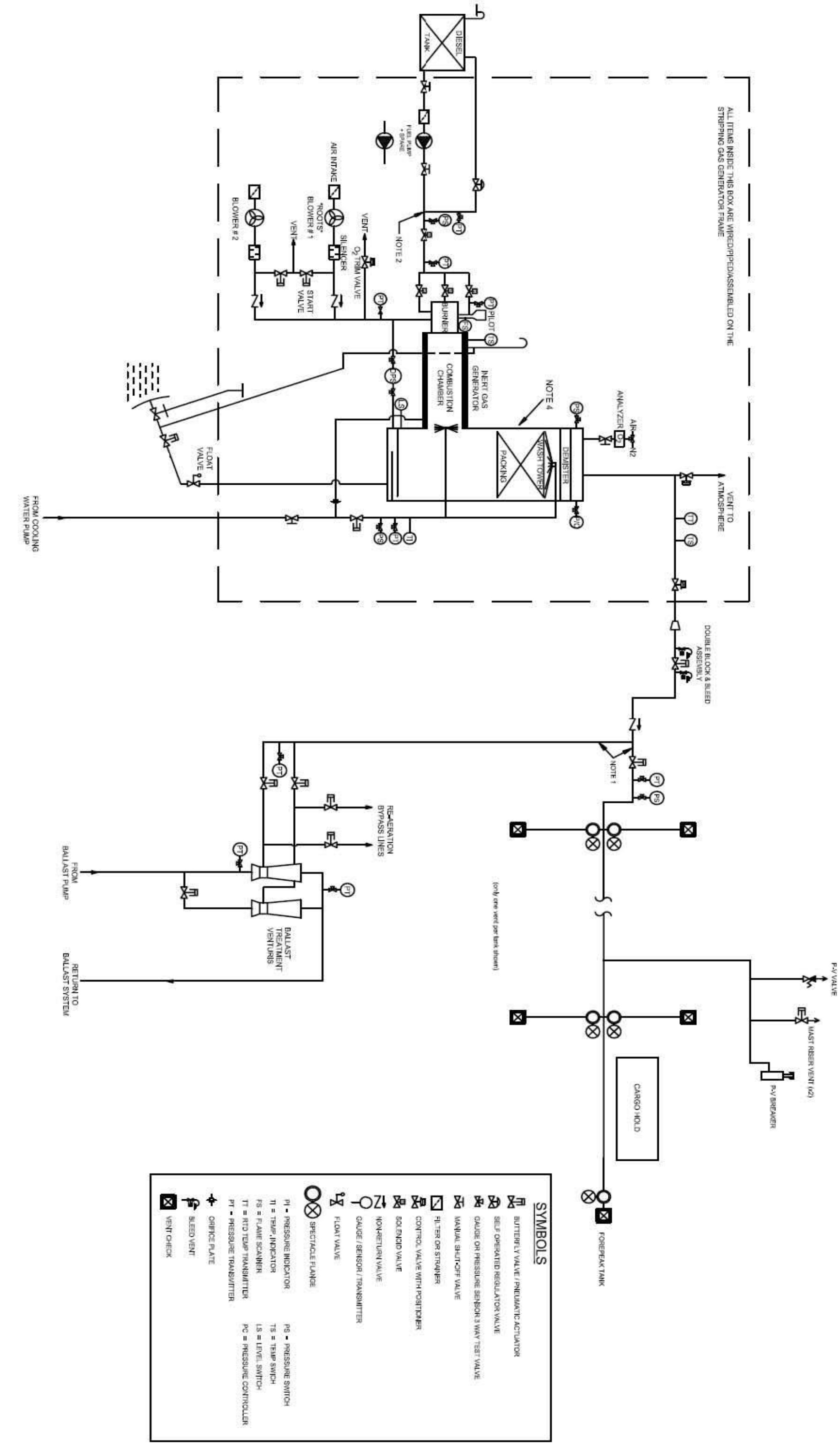
1. Ballast discharged above the water line is re-aerated as it falls and splashes in to open waters.
2. Ballast discharged below the water line can be re-aerated by passing it through the Venturi Injectors with the gas inlet line open to atmosphere. This mixes fresh air with the ballast, re-aerating it before discharge.

**VOS Flow Diagram**

Below is a standard VOS flow diagram showing a schematic layout for a VOS system installation aboard a bulk carrier. **Please note:**

- The Inert Gas Generator/Stripping Gas Generator is installed in the machinery space using installation and operational rules required by Class for Cargo IG systems, as appropriate.
- The Venturi Injectors are installed in a riser loop from the ballast pumps. The VI’s are installed; vertically, inlet down at or close to the height of the top of the ballast tanks. Normal installation location is on deck immediately forward of the house.
- The Deck Gas Line may use a trunk down one side of the hatches and branches across to opposite ballast tanks, or may form a loop around each side of the hatches. The Deck Gas line ties into each ballast tank with a Vented Spectacle Flange installed before each tank for tank isolation, when required.
- Each ballast tank is fitted with two normally closed vents in place of the conventional ball check vents. These vents isolate treated/inerted ballast tanks while allowing full out flow in the event of tank over filling.
- The P/V Valve. P/V Breaker and Mast Vent Risers allow gas to vent during ballasting operations and provide P/V protection to the ballast tanks in the same way as a Cargo IG system.

# EXAMPLE VOS FLOW DIAGRAM FOR A BULK CARRIER



**VOS Installation Pictures**

**Shipboard Venturi Injector Installation**
**Chemical Tanker 500m$^3$/hr, Tusla Turkey**

**Shipboard Venturi Injector Installation**
**320,000 DWT Crude Oil Tanker 6,000m$^3$/hr. new build, Hyundai Korea**

**Stripping Gas Generators being prepared for shipment.**

**Left; 500m$^3$/hr system from Mitsubishi Kakoki, N.E.I. license partner in Japan.**
**Right; 4,400m$^3$/hr system from Samgong Co, N.E.I. license partner in Korea.**


**Deck Gas Piping aboard 36,000DWT Bulk Carrier**


**Ballast Tank P/V Protection aboard 20,000DWT Chemical Tanker**

**VOS Biological Testing – Organization Description**

Founded in 1925 The Chesapeake Biological Laboratory (CBL) is a marine research facility of the University of Maryland Center for Environmental Science (UMCES). It is located on the Western Shore of the Chesapeake Bay, one of the world's largest estuarine ecosystems. CBL is a charter member of the National Association of Marine Laboratories, and an Alliance for Coastal Technologies (ACT) member.

Previous work with deoxygenation and ballast treatment made CBL ideal both from a facilities and academic point of view. CBL was able to bring hardware testing expertise, aquatic invasive species and marine biology expertise together with a thorough knowledge of the ballast treatment issue. In addition, all of these resources were located in the highly productive and biologically diverse natural setting of the Chesapeake Bay.

Founded by an endowment to the Smithsonian Institute in 1964, The Smithsonian Environmental Research Center (SERC) has become one of the Nation's leading research and education centers.

SERC has for a long time been studying and working at the forefront of the invasive species and ballast water treatment issue. SERC has become "*The national center for research on biological invasions in marine ecosystems*". This work includes building up a team and procedures to collect accurate, representative samples of vessels' ballast tanks. To perform complete studies of ballast treatment systems, SERC developed the specialized analytical procedures required to accurately assess the effectiveness of a treatment technology.

SERC is also the manager of the National Ballast Water Information Clearinghouse (NBIC), an information and reporting database run in conjunction with the USCG. This responsibility, as well as others relating to ballast water and invasive species, were mandated to SERC in the National Aquatic Invasive Species Act and its previous forms.

The primary scientific grant applicants and lead investigators in the independent trials of the VOS system were Dr's. Mario Tamburri and Gregory Ruiz. with CBL and SERC respectively. The grants were written and awarded to evaluate the biological efficacy of Venturi Oxygen Stripping (VOS), initially with a land based system and later with a full scale shipboard system. The pilot-scale and full scale evaluations of biological efficacy were designed by Drs. Ruiz and Tamburri, and all tests, sampling, and analyses were carried out by the lead investigators, their staff or qualified/certified outside laboratories.

**VOS Biological Testing - Lead Scientists**

**Dr. Mario Tamburri** is an employee of the State of Maryland and an Associate Professor at the Chesapeake Biological Laboratory (CBL), University of Maryland Center for Environmental Science. He is also the Executive Director of a NOAA funded program - Alliance for Coastal Technologies, which serves as an unbiased, third-party test bed for evaluating the performance of marine environmental sensors. Dr. Tamburri is also involved in several related committees including: Member of the Sensor/Technology Subcommittee for the NSF-funded Ocean Research Interactive Observatory Networks (ORION) program

(2004-present), Technical Committee member for the EPA Environmental Technology Verification (ETV) program development of the Ballast Water Treatment Testing Protocols for the U.S. Coast Guard (2003-present), Technical Advisory Panel member for Ship Structure Committee to examine deterioration of structural integrity due to chemical treatment of ballast water (2002-present).

**Dr. Greg Ruiz** is a U.S. Federal employee and a Senior Scientist at the Smithsonian Environmental Research Center (SERC). He is Director of the SERC Marine Invasions Research Laboratory and also manages the U.S. National Ballast Information Clearinghouse (in collaboration with the US Coast Guard). Dr. Ruiz is also involved in several related committees including: Working Group on Introductions and Transfers of Marine Organisms, International Council for the Exploration of the Sea (2000-present), Study Group on Ships Ballast Water and Other Ship Vectors, International Council for the Exploration of the Sea & International Maritime Organization (2001-present), Global Invasive Species Program (1999-2003), Advisory Committee for National Aquatic and Marine Invasion Clearinghouse (1999-present), Ballast Water and Shipping Committee, and Aquatic Nuisance Species Task Force.

**Biological Testing Responsibilities**

When the CBL, SERC, N.E.I. team was awarded the first Ballast Water Technology Demonstration Program grant, the responsibilities were broken down as follows:

- N.E.I.: Build the 300m$^3$/hr pilot scale system at the CBL facility, and instruct the CBL staff on its operation.
- CBL: Host the pilot scale system, generate trial protocols, primary collection of samples, initial sample analysis, collect and report the findings, overall management of the trial.
- SERC: Support CBL with test protocols, complete dockside cell counts and analysis.

After the successful completion of land-based testing and further grant funding, N.E.I installed a 1,000m$^3$/hr. system aboard the TECO Ocean Shipping ITB Pat Cantrell, a 36,000 DWT bulk carrier. This system was used for shipboard testing of VOS. During shipboard trials SERC's role expanded to include primary sample collection. This is a task in which the Center has developed considerable expertise since the late 1990's, sampling from more vessels on more occasions than any other institution in the world.

**Laboratory Quality Assurance and Quality Control Plans and Procedures.**

All of the VOS trials, both land-based and shipboard, were completed by reputable, government marine biology research institutions; MERC and SERC. Funding for this research was awarded through the securing of competitive federal grants. Testing and analysis was completed by these bodies completely independent of N.E.I. The QA/QC procedures used were the Standard Operating Procedures of these Federal and State testing facilities and laboratories. Below are samples of extensive quality assurance and control materials for these institutions.

The test and QA/QC protocols described below are rigorous and appropriate but completed before specific requirements for BWMS testing were adopted.

The Chesapeake Biological Laboratory (CBL), University of Maryland Center for Environmental Science is the lead institution for the VOS testing grant awards. CBL is also the lead laboratory of eight in a network called the Alliance for Coastal Technologies (ACT). One of the functions of ACT is to perform independent testing on marine based instruments, for review of USCG among others. The facility and its personnel are ideally suited for independently testing N.E.I.'s VOS BWMS.

The two extracts below are from the ACT Technology Evaluation protocol document and the CBL Nutrient Analytical Services Laboratory. They detail the lab's mission and QA/QC procedures.

**Chesapeake Biological Laboratory Field Test Site**

*"The ACT Partner at Chesapeake Biological Laboratory (CBL), University of Maryland Center for Environmental Science, has established a Technology Verification Field Test Site on a fixed pier (Lat: 38°19.039 N, Lon: 76°27.065 W, with an average depth of 7 ft) at the mouth of the Patuxent River, a tributary of the Chesapeake Bay. The Chesapeake is a nutrient rich estuary with a watershed that encompasses portions of six states and the District of Columbia. Water temperatures at the testing location range from 0° to 35°C and salinities range from 5ppt to 20ppt depending on season, rainfall, wind, and other external factors."*

***1. Background on ACT Evaluations***

*Instrument validation is necessary to enable effective existing technologies to be recognized and so that promising new technologies can be made available to support coastal science, resource management and the long-term development of an Integrated Ocean Observing System. The Alliance for Coastal Technologies (ACT) has therefore been established to provide an unbiased, third party test bed for evaluating new and developing coastal sensors and sensor platforms for use in coastal environments.*

*The following protocols describe how ACT will verify the environmental performance characteristics of commercial-ready, in situ dissolved oxygen sensors through the evaluation of objective and quality assured data. The goal of this evaluation program is to provide technology users with an independent and credible assessment of instrument performance in a variety of environments. Therefore, the data and information on performance characteristics will cover legitimate information that users need. ACT will not simply verify all claims of vendors, but instead looks to the broader community to define the data and operational parameters that are valuable in guiding instrument purchase and deployment decisions.*

***7.0 Quality Assurance/Quality Control***

*Technology performance verifications are implemented according to the test/QA plans and technical documents (e, g. Standard Operating Procedures) prepared during planning of the verification test. Prescribed procedures and a sequence for the work are defined during the planning stages, and work performed shall follow those procedures and sequence. Technical procedures shall include methods to assure proper handling and care of test instruments. All implementation activities are documented and are traceable to the test/QA plan and SOPs and to test personnel.*

***7.1 Laboratory Quality Control***

*Both the test and laboratory reference instrumentation to be used in this verification test will be calibrated by the ACT TC at the University of Michigan according to the SOPs for the instrumentation prior to field deployment. Each TC for each instrument will maintain a calibration log. The logs shall include at least the following information: name of instrument, serial number and/or identification number of instrument, date of calibration, and calibration results. These logs shall be provided to the ACT Chief Scientist and maintained in a master calibration file as part of the QA/QC records.*

***7.2. Field Quality Control***

*Field quality control represents the total integrated program for assuring the reliability of measurement data. It consists of the daily field logs, quality control samples, and sample custody procedures.*

***Field Logs** – Standard, uniform field logs should be maintained for all fieldwork. These logs should report name of staff conducting fieldwork, date (month, day, and year), operating status of all equipment, and manual readings of environmental conditions.*

***Field Quality Control Samples** – To ensure that the reference sample collection and analysis procedures are properly controlled, field blanks and laboratory replicate samples will be taken once a week during the test period. These will be analyzed in the same manner as the collected reference samples. Field blanks are sample containers filled with distilled or deionized water that have been saturated with $O_2$, taken to the field, fixed, and returned to the laboratory. These samples assess contamination during transport and storage. Replicate samples determine the variability associated with sample collection.*

***Sample Custody** – All collected reference samples at each test site will be handled in the same manner. All reference samples will be accompanied by the sample collection sheet and chain-of-custody form (see below). Proper labeling of sample bottles is critical. Each reference sample should be dated and coded according to site and sample sequence. The actual sample container should be labeled with a number for identification. The reference sample number should be used in all laboratory records to identify the sample. Transfer of reference samples from field personnel to lab personnel is also recorded and records are maintained in the lab with the names and signature of persons leaving and receiving the custody. Samples stored for any period of time shall be routinely inspected by the TC to assure proper preservation and label integrity. Results of these inspections shall be included in the sample records. All logs shall be duplicated weekly. The original shall be retained at the ACT Partner site and a copy shall be sent to the ACT Chief Scientist.*

### *7.3. Audits*

*Independent of each Partner test facility QA activities, the ACT Chief Scientist will be responsible for ensuring that the following audits are conducted as part of this verification test at a minimum of three ACT Partner test sites. Audits shall be performed by Quality Assurance personnel, who shall be independent of direct responsibility for performance of the verification test.*

***Performance Evaluation Audits** – A performance evaluation audit will be conducted to assess the quality of the reference measurements made in this verification test. Each type of reference measurement will be compared with a NIST-traceable standard that is independent of those used during the testing. This audit will be performed once during the verification test.*

***Technical Systems Audits** – ACT's Quality Assurance personnel will perform a TSA at least once during this verification test. The purpose of this audit is to ensure that the verification test is being performed in accordance with the test/QA plan, published reference methods, and any SOPs used by the Partner test facility. In this audit, the ACT Quality Assurance personnel may review the reference methods used, compare actual test procedures to those specified or referenced in the test/QA plan, and review data acquisition and handling procedures. A TSA report will be prepared, including a statement of findings and the actions taken to address any adverse findings.*

***Data Quality Audits** – ACT's Quality Assurance personnel will audit at least 10% of the verification data acquired in the verification test to determine if data have been collected in accordance to the test/QA plan with respect to compliance, correctness, consistency, and completeness the ACT Quality Assurance personnel will trace the data from initial acquisition to final reporting.*

***Assessment Reports** – Each assessment and audit will be documented, and assessment reports will include the following:*

- *Identification of any adverse findings or potential problems,*
- *Response to adverse findings or potential problems,*
- *Possible recommendations for resolving problems,*
- *Citation of any noteworthy practices that may be of use to others, and*
- *Confirmation that solutions have been implemented and are effective.*

### *7.4. Corrective Action*

*The ACT Chief Scientist, during the course of any assessment or audit, will identify to the ACT Technical Coordinators performing experimental activities any immediate corrective action that should be taken. If serious quality problems exist, the ACT Chief Scientist is authorized to stop work. Once the assessment report has been prepared, the ACT Chief Scientist will ensure that a response is provided for each adverse finding or potential problem and will implement any necessary follow-up corrective action. The ACT Quality Assurance Manager will ensure that follow-up corrective action has been taken.*

Below is an abbreviated copy of the QA/QC procedures for the Nutrient Analytical Services Laboratory. This EPA certified lab completed the analysis of physical parameters such as TSS on the trial waters.

***STATEMENT OF QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES***

*A constant consideration of Nutrient Analytical Services is assuring the quality of data generated by the procedures presented in this manual. Further, indication of data quality is accomplished by analyzing duplicates, spikes, standards-as-samples, standard reference materials and participating in cross-calibration exercises.*

***Laboratory Duplicates***

*Approximately 5% of the total number of samples analyzed consist of laboratory duplicates. For dissolved analytes, after a sample is analyzed, the same sample container is placed farther along in the automatic sampler and re-analyzed. The mean of the two values is reported as the concentration for that sample. If a difference of >10% is observed between replicates, then all of the replicates for that particular analytical run are carefully reviewed. If only one of the duplicate pairs is in question, then only that sample is re-analyzed. If all show a similar trend, then instrumentation/reagent problems are suspected and the analytical run is halted until such time as the problem is resolved. This procedure is practiced for all dissolved analytes that are not consumed completely in the analytical procedure. For those that are completely consumed and for particulate analytes, duplicate samples constitute actual duplicate samples collected in the field and analyzed in the same analytical run.*

*Values for each duplicate analyzed are recorded in a separate QA/QC data file along with the sample number, sample collection date and analysis date. The mean concentration and standard deviation of the replicates are calculated in this data file.*

*In the case of particulate carbon and nitrogen, total suspended solids and chlorophyll a, 10% of the total numbers of samples are analyzed as duplicates. This generates sufficient quality assurance data to compensate for the omission of laboratory spikes for these non-aqueous samples.*

*Laboratory duplicates serve as an indicator of instrument stability, consistency in laboratory sample preparation and analysis, as well as an estimate of field proficiency.*

***Laboratory Spikes***

*Approximately 5% of the total numbers of samples analyzed consist of laboratory spikes. A spike is prepared by adding a known volume of standard to a known volume of pre-analyzed sample. We routinely add enough concentrated standard to provide a significant response on our instruments that is distinguishable from the original concentration of the sample. This concentrated standard is used to minimize any possible change in sample matrix by the addition of spike.*

*The spiked sample is analyzed and its expected concentration calculated as the sum of the original concentration and the spike concentration, normalized for the constituent volumes. A comparison is made between the actual value and the expected value. These concentrations (original, expected and actual) are recorded in a separate QA/QC data file along with sample number, sample collection date, analysis date and the amount of spike added. In the case of particulate phosphorus, the volume filtered is not used in the calculation to determine percentage recovery.*

*If a value of >115% or <85% is observed for percentage recovery of the spike, then all of the spikes for that particular analytical run are carefully reviewed. If only one of the spikes is in question, then only that sample is re-analyzed. If all show poor recovery, then instrumentation/reagent problems are suspected and the analytical run is halted until such time that the problem is resolved. This procedure is adhered to for all dissolved analytes and for particulate phosphorus and biogenic silica.*

***Documentation of Slopes, etc.***

*A running record of the slopes of the standard curves (the so-called "F," "S" and "K" factors) is maintained for each analysis. Random up and down movement within a predetermined range as a function of time indicates the analysis is under control. Consistent upward or downward movement of these factors indicates the analysis is out of control and requires immediate attention.*

***Standard as Sample***

*Standards are analyzed as samples throughout the analytical run. This is an excellent means of evaluating instrument performance during the course of an analytical run. Standards are analyzed every 12 - 20 samples, depending on the instrument and analyte.*

***Limits of Detection***

*detect, have been established for all parameters routinely measured by Nutrient Analytical Services. The limit of detection is 3 times the standard deviation of a minimum of 7 replicates of a single low concentration sample.*

*Results based on a minimum of seven replicates collected from one cubitainer and analyzed randomly on a typical day of analyses.*

***Cross Calibration Exercises***

*Nutrient Analytical Services has participated in many cross calibration exercises. Participation in such programs is an excellent means of determining accuracy of results. Examples of such cross calibration exercises include the Chesapeake Bay Quarterly Split Sample Program, US EPA Method Validation Studies and International Council for the Exploration of the Sea Intercomparison Exercise for Nutrients in Sea Water.*

***Sample Custody***

*Upon arrival at the laboratory, samples are counted, observed for potential problems (melting, broken containers, etc.) and placed in a freezer until analysis. Sample information and date of arrival are recorded on a log sheet.*

***Instrument Maintenance***

*Analytical instruments are maintained on a regular basis and records are kept of hours of operation, scheduled maintenance, pump tube changes, etc.*

*A critical spare parts inventory is maintained for each instrument. Instrument down-time is minimized by troubleshooting instrument problems telephonically with manufacturers and service representatives. Spare parts can be received within 24 hours via next-day air service.*

***Statement on Instrument Comparability***

*No predetermined number of data pairs are used to make the assessment on data comparability between new and existing methodology. Even in the case of instrumentation with similar methods of detection (i.e., automated colorimetric), no specific number of data pairs is used. Comparability at low and high concentrations, salinity and other possible matrix interferences, sensitivity and precision are all factors in determining the number of pairs that must be addressed before bringing an instrument on-line and in determining instrument comparability.*

*The analyst who performs these comparisons should be experienced, open-minded and impartial. This person can give an evaluation of ease of instrument operation and a very important general statement of comparability. This statement on comparability must then be substantiated via statistical analysis of the data. As previously mentioned, these data must encompass the entire concentration range, matrix interferences, percent recovery, results of standard reference material analyses, etc. The data interpretation must support comparability. The analyst and laboratory QA/QC officer must concur and finally, some sort of presentation (written or verbal) must be given to the contractor explaining what procedure was followed and the results that were obtained to bring this instrument on-line.*

***Temperature Logs***

*Temperature logs of freezers, refrigerators and drying ovens are kept on a monthly basis. Thermometers used in this equipment are calibrated against a certified NBS thermometer.*

**CBL VOS TESTING Quality Assurance Project Plan**

CBL ran the trials of the VOS system to their normal rigorous QA/QC protocols (above). Some of the points in the protocol which specifically addressed these trials are listed below:

- All instruments used were calibrated to manufacturers' specifications prior to each trial.
- Redundant instruments were employed to verify specific measures.
- All physical and biological measurements and samples were replicated.
- Physical water sample analysis for parameters such as Chlorophyll, TSS and POC were sent as blind samples with appropriate Chain of Custody to CBL/NASL for analysis using only EPA approved methodologies.
- Biological samples were analyzed blind (between control and treated) by a second technician to remove any possible analyst bias.
- The mortality of zooplankton was double confirmed by removing a sample of apparently dead organisms and placing them in beakers of fresh aerated water. The removed organisms were selected if they appeared to be intact but did not move or respond to physical stimuli. If after 24hrs no signs of life were observed, mortality was confirmed.

**Biological Analytical Testing Techniques**

The specialized zooplankton and phytoplankton cell counts were completed by CBL and SERC. Analysis of physical constituents and bacterial cell counts were completed by the Nutrient Analytical Services Laboratory and Bigelow Laboratories respectively.

**Zooplankton**

Entire zooplankton (>50 µm) samples of treated and control water were examined under a dissecting microscope (prior to fixation) to estimate the proportion of live versus dead organisms using standard and accepted movement and response to stimulus techniques. All zooplankton samples were then also fixed with buffered, 10% formalin and analyzed for total counts and course taxonomic classification under a dissecting microscope.

**Phytoplankton, Bacteria and Physical Parameters**

As a part of the University Of Maryland Center for Environmental Science, the Nutrient Analytical Services Laboratory (NASL) provides high quality analytical services to the University and outside clients. Phytoplankton and protozoa (organisms <50 µm in minimum dimension and ≥10 µm in minimum dimension) were quantified using whole water samples. A sample from each replicate test and control tank was collected at the end of each trial. Total cell counts and chlorophyll concentrations were determined for all samples; sub-samples were also subjected to re-growth assays.

Sub-samples of all phytoplankton and protozoa were fixed with standard Lugol's solution and 1 ml of 10% formalin to determine cell abundances. Samples were settled for 24 hours using an Utermohl counting chamber and analyzed with an inverted compound microscope under phase contrast illumination. While useful for a conservative estimate, it is critical to note that it cannot determine living cell counts.

NASL also completed analyses of Chlorophyll, Total Suspended Solids (TSS) and Particulate Organic Carbon (POC).

The Bigelow Laboratory for Ocean Science is a federally supported research laboratory dedicated to marine research, specifically the interdependencies of different marine systems. The Bigelow Laboratory pioneered the flow cytometry analytical equipment and techniques which allow accurate phytoplankton and bacteria cell counts. The laboratory has remained at the forefront of this now internationally accepted technique. Bigelow Lab completed quantitative analysis for bacteria for the VOS trials.

E. coli and Enterococci bacteria were both analyzed using IDEXX analytical sets. IDEXX is a U.S. based company which has developed a reliable and successful line of highly accurate field tests for many drinking water contaminants and pathogens. The IDEXX kits for both E. coli and Enterococci are EPA approved and standard practice for U.S. drinking water applications. The method employs ASTM D-

6503-99 for biological water pollution. The test sets have approvals for use from many different countries as well as the World Health Organization.

**Land-Based Testing Overview**

After successful lab scale testing N.E.I. built a 300 $m^3$/hr. VOS system the CBL facility in Solomons, Maryland.

**Pilot-Scale VOS system at the Chesapeake Biological Laboratory, Solomons, MD.**

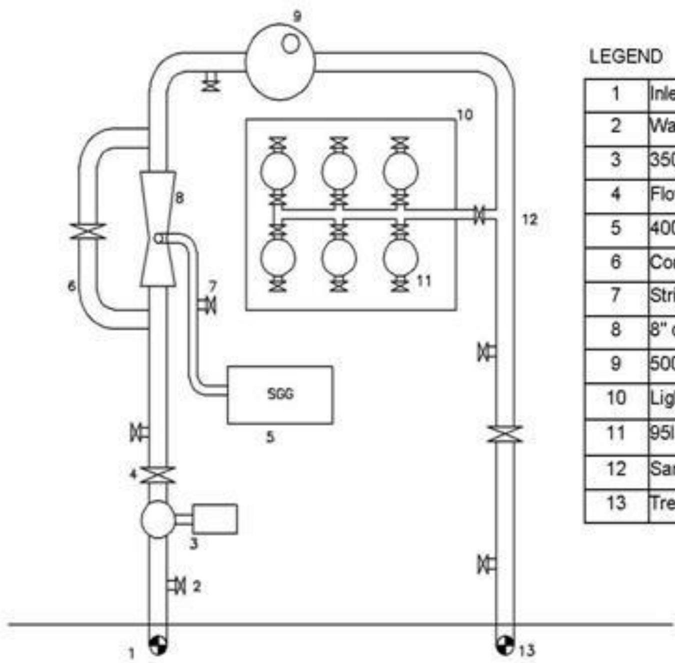
The pump (blue) is pictured in the foreground with the stainless steel SGG behind it. The PVC pipe from the top of the IGG leads to the 200 mm (8 inch) Venturi Injector mounted in the 200 mm PVC pipe, surrounded by the bypass line, used when collecting control samples.

Experimental design incorporated the IMO G8 guidelines and involved comparing the abundances of organisms in control versus treated water against IMO standards. A total of 18 separate biological test runs were conducted between April 2004 and October 2005, to evaluate the ability of VOS to kill naturally-occurring planktonic organisms and bacteria. Trials were conducted to assure consistency between seasons and years, while challenging the treatment as much as possible with abundant and diverse natural assemblages of plankton.

For the land-based testing, CBL did not collect “ambient” organism counts, only control and treated. Ambient counts would have differed from control because they would have been collected directly from the bay and not pumped to the sample collection tank. Even so, the numbers and diversity of organisms were far greater than the IMO Guidelines.

Below is a schematic diagram of the pilot scale VOS test setup illustrating the component layout and process flow of the system:

LAYOUT OF PILOT SCALE SYSTEM AT
CHESAPEAKE BIOLOGICAL LABORATORY




LEGEND

| | |
|---|---|
| 1 | Inlet water draw from 8' below surface |
| 2 | Water Sampling Port (typ.) |
| 3 | 350m3/hr centrifugal water pump |
| 4 | Flow control valve (typ.), 8" butterfly valve |
| 5 | 400m3/hr Stripping Gas Generator |
| 6 | Control water by-pass line |
| 7 | Stripping gas conveyance piping 2" dia |
| 8 | 8" dia 316 stainless steel venturi injector |
| 9 | 500 gallon water tank simulates contact time for full scale system |
| 10 | Light proof sample containment |
| 11 | 95l sample storage tanks |
| 12 | Sample port; sampling completed by hand pump |
| 13 | Treated water discharge point, above surface |

The land-based test system consisted of a 300 $m^3$/hr. (1,500 gpm) centrifugal water pump, 200 mm (8-inch) diameter PVC piping, a 200 mm (8-inch) diameter Venturi Injector, and a full scale SGG, previously used on board ship by the Alaska Tanker Company as an IG Topping Generator.

From the tank (9 above), water flowed by gravity through another 200 mm PVC pipe and was either collected as part of a hand pumped 25 gallon sample or was discharged back to the bay. The system operated at 300 $m^3$/hr. Discharge, without permit was approved by the State of Maryland's Department of the Environment.

The land-based VOS system was an accurate model of the shipboard equipment. The 200 mm (8 inch) diameter Venturi Injector performed as well as both the ¾-inch units used in bench scale testing and the 300, 400, 500 and 600mm (24-inch) units subsequently used in actual production shipboard installations. Deoxygenation is completed in the same time frame (less than 10-seconds) regardless of the scale of system used.

For sample containment CBL used specifically prepared 95 liter (25-gallon) cone bottom tanks, designed for growing plankton stored in the dark. These were housed in the structure shown in the photograph above.  A hand powered diaphragm pump was used to collect each sample. Slow deliberate actions removed the possibility of sample collection influencing live count results. Throughout the 18 months of trials, the SGG and the Venturi Injector performed as expected-fully treating all samples to below IMO guidelines.

**Land-Based Trial-Data Collection**

Physical (temperature, salinity, dissolved oxygen and pH) and biological parameters (zooplankton abundance, Chlorophyll-a concentrations, *Escherichia coli* and *Enterococci* concentrations) were measured in the Bay where water was drawn at the beginning of each test run. During several test runs, ambient Bay water was collected for particulate organic carbon (POC) and total suspended solids (TSS).

The epoxy sample tanks were arranged in two groups of three in a dark environment. This arrangement allowed triplicate treated and control samples to be collected at the same time and kept in identical conditions.

The three paired control and treated mesocosms were sampled at the end of the prescribed holding times. Zooplankton were examined in >50 µm samples that were collected by slowly filtering the entire volume of each replicate mesocosm.  Phytoplankton and protozoa (organisms between 10 and 50 µm in size) were quantified using whole water sub-samples taken from the center of each well-mixed mesocosm. Finally, total bacteria abundances and concentrations of viable *E. coli* and *Enterococci* were determined from similar sub-samples (see *Analytical Testing Techniques*).

Measurements were also taken to quantify impacts of VOS-treated water on receiving water. Periodic measurements of the temperature, salinity, dissolved oxygen, and pH of ambient water at varying distances from the discharge pipe were taken. These evaluations demonstrated there is essentially no measurable change to receiving water (*please see Appendix-J for full report and data*).

**Land-Based Trials –Results**

The organism counts from the trials were collected at the time of discharge for both the control and treated samples. No pre-treatment organism counts were completed - except for bacteria counts.

**Pilot Scale System VOS Test Results Tables**

The organism counts in these results tables are simple averages for the triplicate samples of treated and control water. Where > (greater than) numbers are indicated in the phytoplankton cell count tables they are very conservative estimates of live cells, after quantitative chlorophyll extraction and regrowth procedures. Subsequent full-scale land and shipboard testing proved all organisms were treated to the IMO guidelines.

**72 hour holding time**

| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml |
|---|---|---|---|---|
| Control | 17,809 | >> 100 | <10 | 48 |
| Treatment | 3.5 | > 10 | <10 | 20 |

**96 hour holding time**

| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml |
|---|---|---|---|---|
| Control | 39,316 | >> 100 | <10 | <10 |
| Treatment | 7 | 0 | <10 | <10 |

**96 hour holding time**

| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml |
|---|---|---|---|---|
| Control | 35,009 | > 100 | 109 | 48 |
| Treatment | 0 | < 10 | 21 | 20 |

**120 hour holding time**

| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml |
|---|---|---|---|---|
| Control | 26264 | >> 100 | 38 | <10 |
| Treatment | 0 | 0 | 21 | <10 |

**120 hour holding time**

| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml |
|---|---|---|---|---|
| Control | 37504 | > 100 | <10 | <10 |
| Treatment | 0 | < 10 | <10 | <10 |

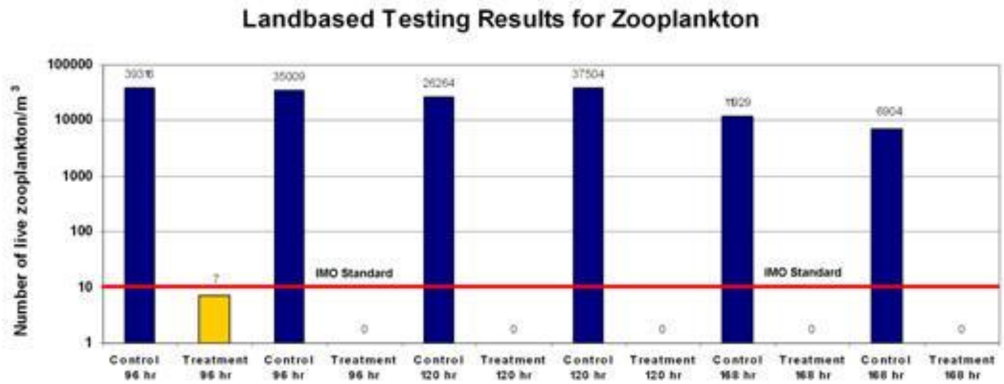
**168 hour holding time**

| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml |
|---|---|---|---|---|
| Control | 11929 | 0 | N/A | <10 |
| Treatment | 0 | 0 | N/A | <10 |

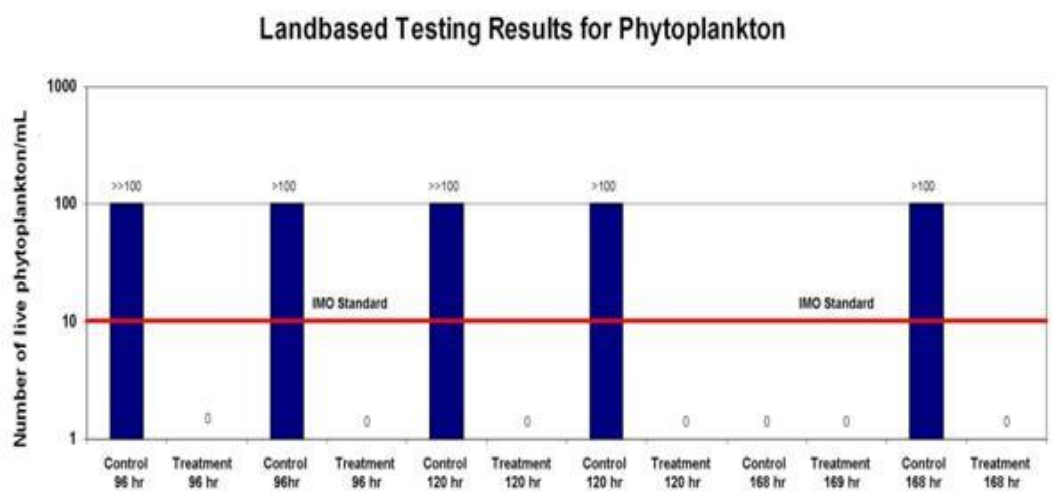
**168 hour holding time**

| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml |
|---|---|---|---|---|
| Control | 6904 | > 100 | <10 | <10 |
| Treatment | 0 | 0 | <10 | <10 |

The results for Zooplankton counts are graphically presented below. The vertical scale of this figure is logarithmic. The consistent and successful results of these trials are clear.




The results for Phytoplankton counts are presented below. The control counts are represented as < than or << than indicating the analyst determined, given the appearance of the sample and the chlorophyll concentration, there were either greater than or much greater than the indicated number of live phytoplankton organisms in the sample. The vertical scale of this figure is logarithmic. The consistent and successful results of these trials are very clear.



**Fresh Water Trials**

VOS is a physical water treatment dependent on creating certain physical conditions. When these conditions are created, treatment will always occur. VOS treatment using Henry's law is independent of water type or water chemistry. Variables such as salinity, turbidity or temperature will not change the treatment mechanism of VOS. To prove this physical process, VOS was tested on completely fresh water (salinity 0 ppt salt, 0 PSU) with fresh water from Lake Lariet Maryland, under the management of MERC and Dr. Mario Tamburri.

Lake Lariet is located six miles from the MERC facility, and is a thriving environment, with an abundance of diverse biology. The samples collected for these trials contained untreated zooplankton counts as high as 402,000/m$^3$. Samples were collected from the lake and quickly transported to the MERC facility where the VOS tests were completed in the controlled environment.

**Fresh Water VOS Test Results Table**

**96 hour holding time**

| Organism | <50 µm/m$^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton*) | *E. coli* /100ml | *Enterococci* /100ml |
|---|---|---|---|---|
| Untreated | 60,000 | > 100 | 3 | 0 |
| Treatment | 0 | 0 | 2 | 1 |

The fresh water testing confirmed VOS's deoxygenation mechanism is independent of salinity and VOS is just as effective in 0 PSU fresh water as brackish or salt water.

**High Saline Artemia Trials**

Several groups believe brine shrimp *Artemia* sp. are valuable to establish the efficacy of BWMS's because they are a particularly hardy form of zooplankton (i.e., high tolerance for extreme environmental conditions). Brine shrimp can thrive all over the world. The common *Artemia franciscana* was therefore hatched, raised, and tested for response to the VOS treatment, at their optimal living conditions (25$^{o}$C and 34 ppt) under the laboratory conditions.

***Artemia* VOS Test Results**

| Organism | Live *Artemia* / $m^3$ after 24h | Live *Artemia* / $m^3$ after 48h |
|---|---|---|
| Untreated | 121,000 | 82,000 |
| Treatment | 1,667 | 0 |

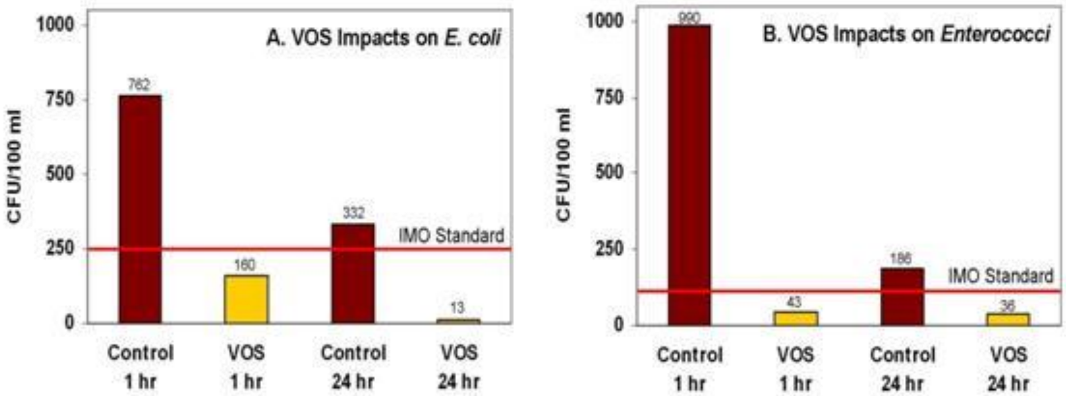
The Artemia trials prove the VOS system is completely effective against one of the hardiest common zooplankton organisms known. The results prove the same degree of system efficacy as all other VOS results for Zooplankton. After 24 hours there was a ~99% die off of organisms. After 48 hrs. there were no organisms living. Again, in 48-hours, water subject to the VOS treatment exceeded the USCG Phase 1 and IMO D-2 discharge standards.

**Bacteria Trials**

Though there were normally millions of bacterial cells per ml in the Chesapeake Bay water, few were *Enterococcus* or *E. coli* bacteria. To prove VOS is effective treatment for these bacteria CBL completed some bacteria specific tests, using seeded samples.

Abundances of *E. coli* (A) and *Enterococci* (B) in seeding experiments with control (n = 3) and VOS treated (n = 3) water after either 1 hour or 1 day holding periods without light. In separate experiments, single strains of bacteria were cultured and added to 50 L of natural bay water at approximately 800 cfu/100 ml. The seeded water was pumped into replicate 1 L flasks, with control flasks open to air and treated flask sealed to maintain hypoxic conditions. One 100 ml subsample from each flask was analyzed for concentrations of culturable *E. coli* or *Enterococci* using a commercially available chromogenic substrate method (IDEXX Laboratories, Inc.; Noble et al. 2003).

**Seeded Bacteriological Test Results**




The results of the bacteriological trials are presented above. The successful treatment of these samples is consistent with all other VOS trials; compliance is achieved quickly and consistently when a de-oxygenated environment is created. The shipboard trials of VOS once again confirmed these lab results. Bacteria generally can thrive in a treated ballast tanks because the dead organisms provide an abundance of food for the bacteria to feed upon.. However, the deoxygenated environment created by VOS does not allow this to happen, <u>bacteria do not bloom when held in VOS treated tanks</u>.

*Vibrio cholerae* is also a regulated bacterium; however it did not occur naturally in the pilot scale testing. Therefore, the testing for *Vibrio cholerae* was conducted during the shipboard trials, under the management of MERC and Dr. Tamburri. In one trial a moderately high count of 2,600 CFU per was detected in 100 ml of ballast water.. Treatment was 100% successful, with no colonies measured in the corresponding treated sample. *Vibrio cholerae* has been documented to be intolerant to rapid changes in DO concentration, VOS is 100% effective.

**Shipboard Testing Overview**

After land-based testing proved VOS capable of meeting the IMO D-2 discharge standards using all types of water; fresh, brackish and salt, rigorous test plan was proposed and additional funding was awarded to the CBL/SERC team for shipboard evaluations of VOS. SERC completed most of the field work and analysis.

N.E.I. worked with TECO Ocean Shipping to install a 1,000m$^3$/hr VOS system aboard the 36,000 DWT bulk carrier "*Pat Cantrel*" This vessel trades primarily in the Gulf of Mexico and Florida's Atlantic coast. The installation was designed to operate with one of the vessel's two 1,000 m$^3$/hr. ballast pumps allowing control and treated samples to be pumped from the sea chest at the same time.

Collecting treatment and control samples simultaneously is just as critical as measuring water conditions when testing a BWTS. The water surrounding a ballasting vessel can change significantly during a single ballasting event.  For example, during testing in Ft. Lauderdale Harbor, the water changed salinity from 18 to 27 PSU during a single ballast event. If the control and the treated samples had been collected at different times, the nature of the water and therefore the organisms would have been very different. It is demonstrative of the efficacy of the VOS system that no account of this significant change in salinity needed to be made for the VOS system to complete treatment as the salinity changed.  A dynamic environment such as the one described above is common throughout global trade routes.  With the VOS system this dynamic nature will not negatively impact treatment.

**Shipboard Testing; specific configuration**

A 1000m$^3$/hr. VOS system was installed including two 300 mm Venturi Injectors; pictured below.

Two identical ballast tank pairs were selected for evaluations of VOS: port tanks 3 and 4 were designated as control and starboard tanks 3 and 4 were designated as treated. During the trials the vessel ballasted normally, with no change in ballasting rate.

After installation and commissioning the test system ran as intended on all occasions when testing. There were no reported equipment failures for the full duration of testing and voyage. The quality of the inert gas remained constant, and the VI's performed as expected throughout. Though the VOS system is not in constant operation, all ballast water always flows through the VI's as they are installed in-line, this is the simplest method of completing the installation. The crew monitored and documented every ballast event during this testing.  There were no detrimental effects to the ballasting process, the ballast pump itself, piping, stripping, etc.

**Note:** After three years the test installation was removed from the Pat Cantrell, 100% of the vessel's ballast water had been pumped through them for three full years. The Venturi Injectors are in perfect condition and used "as is" as VOS display pieces around the world. There are no detectable signs of corrosion or wear in or on the VI's.

**Shipboard Testing – Route and Data Collection Procedures**

The evaluation was undertaken with voyages from the Port of Jacksonville (ballast water collected from the Saint John's River, Florida) to either Port Arthur or Houston, Texas. One measure of note was the high number of >50 µm sized organisms counted in the control, untreated, ballast water. At >500,000/m$^3$ this was the largest concentration of such organisms the sampling team had ever seen. No other conditions or events occurred during the shipboard trials which were of particular note or that may have influenced the trials in any unusual way.

Because VOS does not require a secondary treatment (retreatment), final treated samples were collected from the ballast tanks in the same manner as all other collections. This preserved continuity of procedures, and sample collection consistency throughout the trial. It does mean the samples were not passed through either the VI or ballast pump for a second time, removing any additional physical treatment this may bring. Each final sample was collected with the same highly practiced ballast tank sampling technique as the other ballast tank samples. This is a conservative approach developed by SERC, intended to prevent any damage to potentially still viable organisms.

For each sampling event a total of four samples were collected from each tank; two shallow, and two deep. The shallow collection was documented at 1m below the top of the in-tank water, and the deep sample was documented at 1m above the bottom of the tank. This sample collection plan was developed to account for any possible vertical variation in both oxygen levels and organisms.

Initial concentrations of zooplankton in ballast tanks were remarkably high at levels between 100,000 - 500,000/m$^3$ in individual samples. Total organism count between 10 and 50 µm (phytoplankton/protozoa direct counts under a microscope) in the initial ballast water, during the two test voyages, counts ranged from 1,000 to 3,500 per ml. As with the land-based testing, bacterial counts in the untreated ballast water were in the millions per ml.

Zooplankton were examined in ≥50 µm samples that were collected at each time period using a specially designed and calibrated system developed and constructed by The Smithsonian Environmental Research Center. Total abundance and course taxonomic classification were determined for all samples and time of discharge samples were quantified for live and dead zooplankton.

Phytoplankton and protozoa (organisms <50 µm in minimum dimension and ≥10 µm in minimum dimension) were quantified using whole water samples rather than in situ selective filtration. Two replicate 2-l Kimmerer bottle samples were taken in each test tank near the surface and near the bottom. Total cell counts and in vivo chlorophyll concentrations were determined for all samples. All discharge samples were also subjected to regrowth assays.

Total bacteria concentrations were determined for sub-samples taken from the Kimmerer bottles and discharge samples were also analyzed for concentrations of viable *Escherichia coli*, *Enterococci* and *Vibrio cholerae*.

Measurements were also taken to quantify potential impacts of VOS treated water on receiving harbor water. Dissolved oxygen, pH, temperature and salinity measurements were taken 10 minutes prior to (i.e., ambient water) and 15 minutes after the *Pat Cantrell* began discharging VOS treated water (dissolved oxygen <1.0 mg/l and pH approximately 6) at approximately 1,000 $m^3$/hr. Measurements were taken at the discharge point, and then again at 3 meters horizontally in both directions away from the sea chest. Please see *Appendix-H* for the full MERC shipboard testing report.

**Confirming Dissolved Oxygen Concentrations in treated Ballast Tanks – Pat Cantrell**

**Shipboard Testing Results**

The numbers in the trial results, below, represent averaged organism counts in samples collected from control tanks initially and treated tanks at discharge.

**Shipboard VOS Test Results Tables**

**Jacksonville to Houston**

| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml | *V. cholera* /100ml |
|---|---|---|---|---|---|
| Control | 19,311 | >> 100 | N/A | N/A | 0 |
| Treatment | < 30* | 0 | <10 | <10 | 0 |

**Jacksonville to Port Arthur**

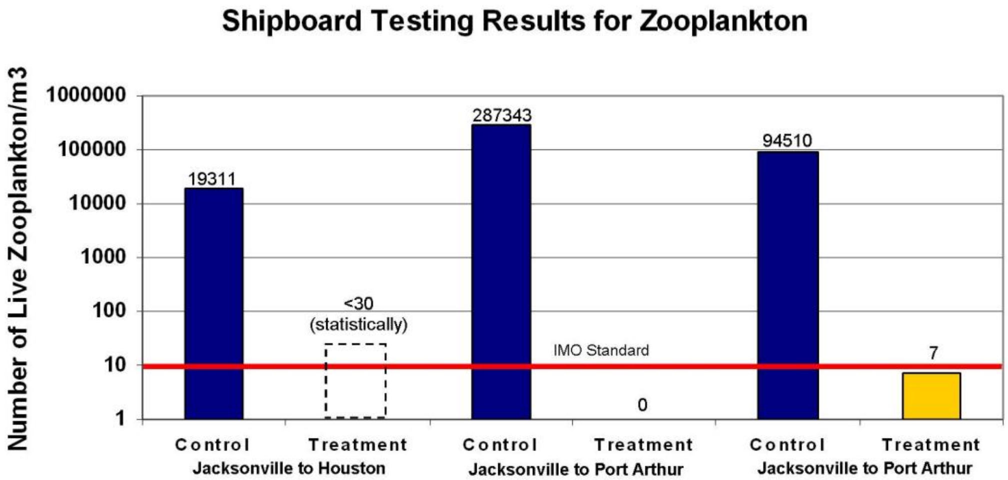
| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml | *V. cholera* /100ml |
|---|---|---|---|---|---|
| Control | 287,343 | >> 100 | N/A | N/A | 2,600 |
| Treatment | 0 | < 10 | N/A | N/A | 0 |

**Jacksonville to Port Arthur**

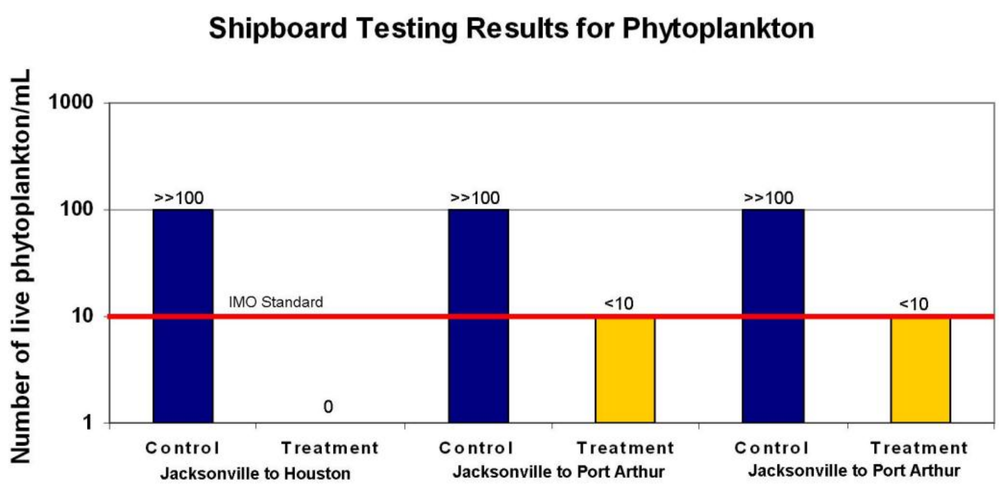
| Organism | <50 µm/$m^3$ (Live Zooplankton) | 50-10 µm/ml (Live Phytoplankton) | *E. coli* /100ml | *Enterococci* /100ml | *V. cholera* /100ml |
|---|---|---|---|---|---|
| Control | 94,510 | >> 100 | N/A | N/A | 0 |
| Treatment | 7 | < 10 | 29 | <10 | 0 |

N/A The count was not completed for this sample.

* The presentation of this result as <30 is the consequence of an elevated detection limit for the sample size between run #1 and run #2. At the time SERC did not have the ability to reach a level of granularity now possible. Between run #1 and run #1, the analytical capability was brought up to current standards, enabling SERC to present very granular data. <u>The sample did not return a count greater than the IMO standard.</u> Subsequent analyses on runs #2 and #3 utilized the updated techniques, which confirmed the VOS system was treating at or better than the USCG/IMO standards. NEI is presenting the raw data below for ALL runs.




NOTE: The graph above presents the raw data from three separate shipboard trials. The first trial utilized statistical methods not capable of presenting a more precise result than "less than 30". For trials 2-3 this was updated. The updated method supported all previous lab and land-based testing results.




The shipboard testing confirmed the results documented by MERC during lab and land-based testing, fresh water testing and VOS pilot scale testing. More than merely confirming previous biological test results, the shipboard tests prove VOS is a true (this vessel was in-service and conducting normal operations) ballast water treatment system; Capable of full efficacy while normal shipboard operations continue. The system was proven to work onboard an operational vessel, with no impact to the ballasting operations or the normal non-ballast operations conducted throughout the voyage. Since the testing has been completed this has been proven on multiple VOS installed vessels ranging from 7,700 DWT to 320,000 DWT.

# Environmental Testing

In June 2012 the USCG published the final rule for ballast water treatment. The Rule includes specific requirements for environmental testing of*; "The electrical and electronic components, including each alarm, control and monitoring device of the BWMS."*

At the time, the only Independent Laboratory approved to conduct this environmental testing was the Retlif Testing Laboratories, New York. All Testing was completed by the IL as described in 46 CFR 160.060-30. In March 2013, nine days of intensive testing resulted in The VOS electrical and control system passing 100% of the test criteria, to our knowledge to only BWMS to do. Please see *Appendix-D* for full Retlif report

**Environmental Testing Overview**

Twenty one separate components were subjected to the complete set of prescribed tests, from; SGG burner controller and flame scanner, HMI Screens and PLC Controller to Pressure Transmitters and Limit Switches.

**Components Subject to Environmental Testing**

Control Consolet
IC RXI-Controller
IPC-HMI PC
I/O J Box Assembly
Burner Controller
Flame Scanner
Oxygen Analyzer
Dissolved Oxygen Probe
Fuel Solenoid Valve
Pneumatic Solenoid Valve
Pressure Transducer
Pressure Transducer
Pressure Transducer
Pressure Switch
Float Switch
Butter Fly Valve
Butter Fly Valve Actuator
Butter Fly Valve Positioner
Temperature Switch
RTD
Motor Starter (SGG Blower)

Most components are fairly common from established manufacturers; GE, Tyco, Honeywell etc. and have certifications which mean they have passed certain levels of environmental testing. However, the USCG requirements are unique and in some cases beyond more commonly used certification requirements. To comply with the CFR there was no alternative, other than to complete this extensive round of testing with the full list of components used by VOS.

**Environmental Testing - Data Collection**

As required by the Regulation the same components were subjected to each applicable test, these were completed in a sequence dictated by the CFR. After each test the function of each component was verified, witnessed and then recorded.

**Retlif's new inclination table was built specifically for this USCG test**
**Picture shows VOS components installed on N.E.I.'s subframe mounted on the new inclination table**

**USCG required ingress testing (less technical)**

**Temperature and humidity testing:** The screen and controller were kept outside the "oven" with machinery space and outside components being tested inside. Wires passed through the gland allowed the control panel to confirm continued operation of the components inside the oven.

### Environmental Testing Results

VOS completed the testing without any issues. The table below is extracted from the full Retlif Report**.** The entry “Complied” under Test Results prove the individual components all worked correctly both individually and networked correctly to allow the system to “compile”.

These conclusive results from the IL, demonstrate full compliance with the regulations, and again prove that the VOS system in production today is ready to serve in the marine environment, without disrupting vessel operations. Please see attached *Appendix-D* for full Retlif report.

| Testing Dates | Test Method | Component Number | Test Results |
|---|---|---|---|
| March 11 - 13, 2013 | Vibration | 1 through 19 | Complied(1) |
| March 14, 2013 | Temperature, Open Deck | 9, 10, 14, 15, 16 | Complied(1) |
| March 14, 2013 | Temperature, Interior Controlled | 1 through 19 | Complied(1) |
| March 15, 2013 | Humidity | 1 through 19 | Complied(1) |
| March 18 - 19, 2013 | Ingress - Dust | 9, 10, 16 | Complied(1) |
| March 19, 2013 | Ingress - Water | 9, 10, 16 | Complied(1) |
| March 21, 2013 | Voltage Variation | 1 through 19 | Complied(1) |
| March 21, 2013 | Inclination | 1 through 19 | Complied(1) |

# Corrosion and Coating Testing

Corrosion is a critically important issue for a BWMS. Many types of effective water treatment, if used in the BWMS application will “treat” (corrode) ship coatings and structure as well as the organisms they are designed to kill. These established water treatment systems generally increase the oxidative potential in the treatment environment. If an oxidizer is present, it will be oxidizing. This is regardless of material or organism. The oxidizer does not comprehend the differences between bacteria, steel or epoxy coating.

VOS reduces the oxidative potential inside the ballast system, reducing the amount of corrosion seen on bare steel and preserving coatings to a point beyond normal vessel design life. This is particularly true where they are physically damaged. The ability to bring a significant secondary benefit to a vessel, one which can increase safety and reduce maintenance costs, is unique to VOS among all certified BWMS.

In addition, the ability to essentially halt corrosion of older vessels and those vessels with impact damage from operations, adds to the safety benefits of VOS. The ability retard corrosion by up to 85% AND inert the ballast environment is a significant benefit to the owner/operator of any vessel.

**Corrosion Testing Overview**

Rigs and procedures were established to complete corrosion testing of bare and coated steel plates, under de-oxygenated and “normal” conditions Two types of coatings were tested; coal tar epoxy and modified epoxy were used in the current program. Four ballast tank conditions; submerged, humid, buried and splash zones, were simulated in the corrosion testing program. Tests were carried out for 30, 60, 90, 120, 150, 180 and 270 days using simulated sea water of 35 ppt salinity. Dissolved oxygen, pH and the tank head space oxygen were monitored during the entire 270 day test program.

The test apparatus consisted of one 600 liter horizontally split Polytuff container, filled with 280 liters of salt water. This tank acted as the control. The de-oxygenated tank was designed and built using a fabricated rectangular steel tank with a Plexiglas lid. A Polytuff container was then placed inside the steel tank and completely sealed from atmosphere. The Polytuff containers were connected by a shaft turning two 800 mm diameter wheels. These wheels were fitted with sample coupons and rotated to simulate the splash zones in a ballast tank. Salt water at 35 PSU, was used in both the tanks.

Tank-1 was filled with de-oxygenated water, sealed and continuously exposed to the same inert gas environment used on a vessel, to maintain the head space oxygen concentration around 1%. Water was de-oxygenated using N.E.I. Treatment System’s patented Venturi Oxygen Stripping system. Tank 2 was the control tank filled with aerated water exposed to ambient air.

**Material Subject to Corrosion Testing**

The bare steel coupons were mild steel corresponding to the standard Grade “A”, shipbuilding steel as per classification society standards, American Bureau of Shipping (ABS) designated Grade A steel, was used for the test coupons. The specimens were sandblasted to remove mill scale, corrosion products or grease. Test coupons are usually sized to be 75 mm x 125 mm, this size was used for these tests.

Coated coupons used the same steel base and two different paints; Coal Tar Epoxy and Modified Epoxy, from two manufacturers, International Marine Coatings and Jotun Paints Inc. Both paint systems are typically used for new building and coating repairs. Coated coupons were grit blasted to a white metal finish before the application of the primer. Zinc-rich primer was applied to the grit blasted surface of the steel coupons. Coatings applied in the laboratory tend to be of higher quality than those applied in the field and contain fewer defects and holidays. The coatings were scribed, as recommended in ASTM D1654-92 [1], to introduce gross reproducible defects that clarify the role of the damaged coating in protecting the underlying steel.

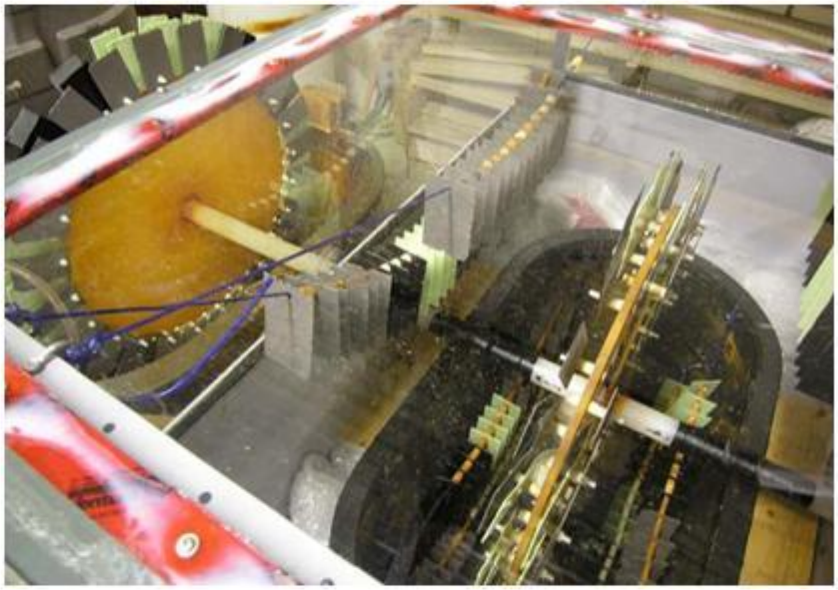
### Corrosion Testing Environments

The test coupons were subjected to simulated ballast tank environmental conditions:

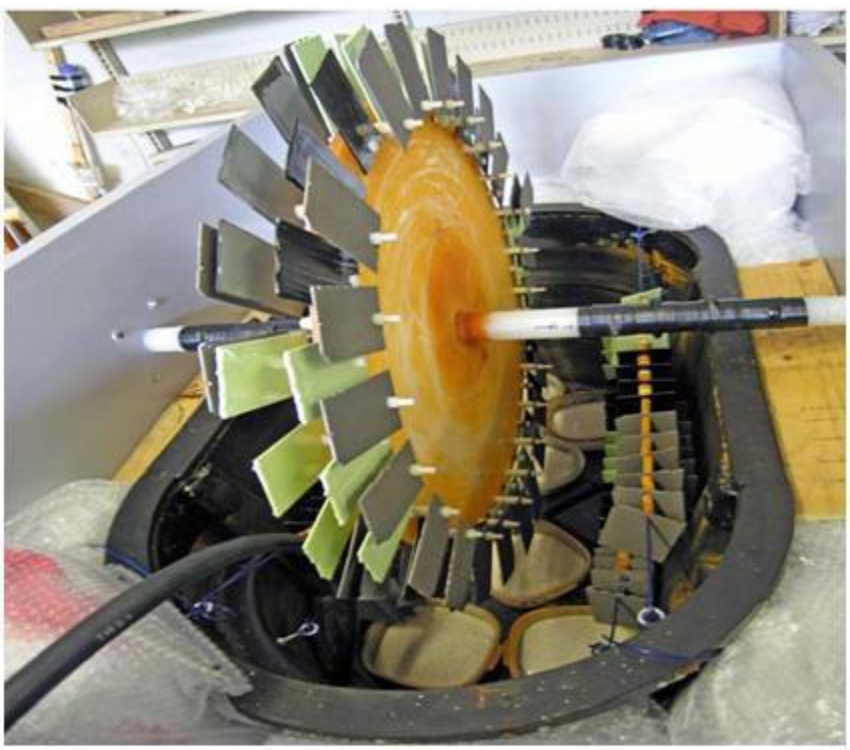
- Splash zones;
- Fully immersed (submerged);
- High humidity; and
- Buried.

- **Splash zone** - Specimens were attached to the rotating wheel using plastic fittings and the coupons were subjected to repeated, complete immersion throughout the test corresponding to the splash action at the waterline of a ballast tank.
- **Submerged** – Specimens were suspended on a cord with each plate separated by plastic spacers and hung in the water filled portion of the tank. These specimens remained fully immersed throughout the corrosion test.
- **High Humidity** – The specimens were mounted like the submerged samples, but hung in the humid vapor-filled space immediately above the water, they were not directly exposed to the salt water.
- **Buried** – Specimens were placed in small plastic containers filled with inert sand. The containers were placed on the bottom of the tanks to simulate the effects of debris on the bottom of the ballast tank. These samples would be expected to experience less severe oxidizing conditions and correspondingly lower corrosion rates.

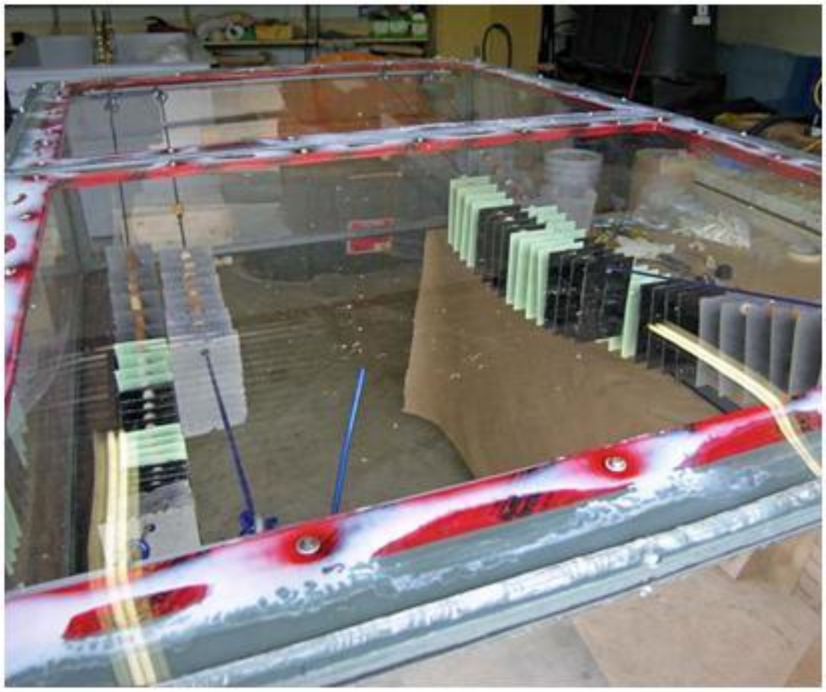
**Test tanks; open to air, left, and VOS treated with cover on the right**



**Test Tank 2, Control, with Splash Zone wheel mounted**



**Test Tank 1, Treated, with test coupons installed**
**Submerged Zone, left, and Humid Zone right**



**Corrosion Testing Results**

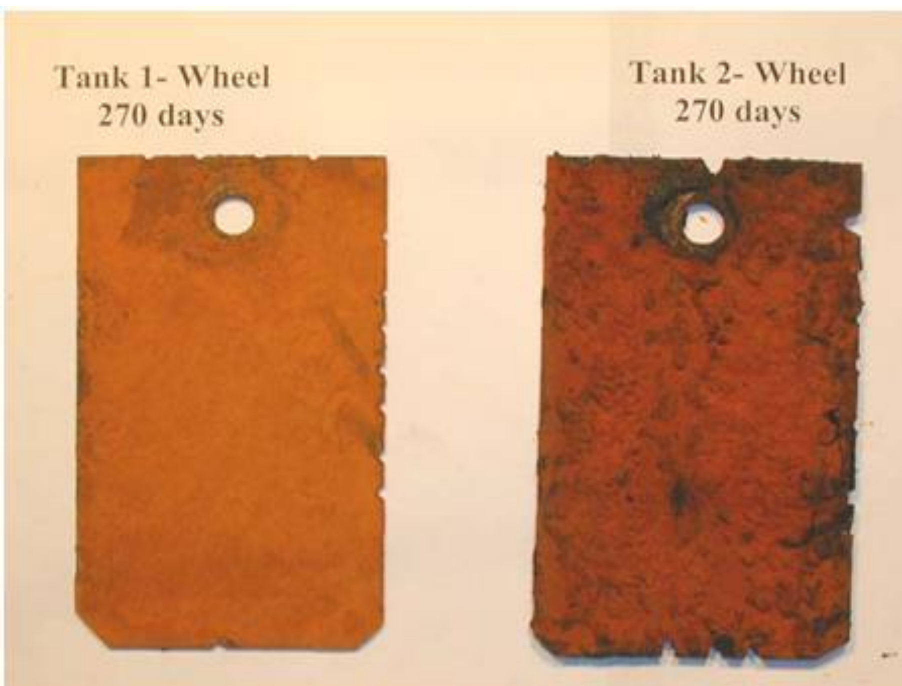
After 270 days of corrosion testing, the corrosion rates were reduced by approximately 75% in humid environment and by approximately 25% in splash zone environment under de-oxygenated condition as compared to control conditions. This translates to a corrosion rate of 0.55mm/yr. on the humid zone coupons in the Control Tank and only 0.09mm/yr. in the Treated tank. The large reduction in corrosion, particularly in the tank top areas of a vessel is very significant to the safety and life of a vessel.

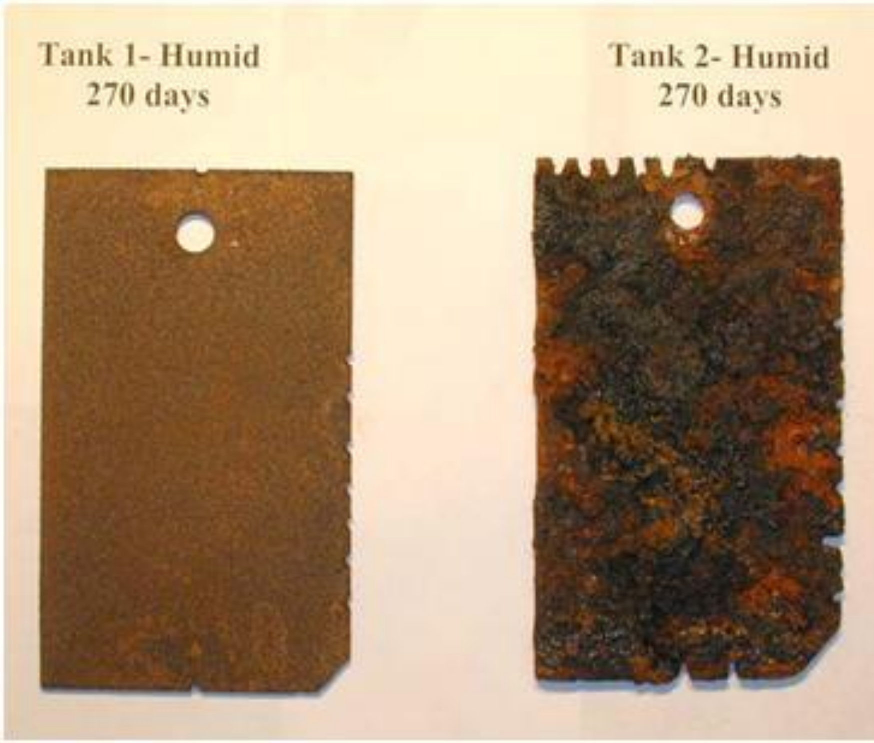
After 270 days, the corrosion rates were similar under submerged environment for both the de-oxygenated conditions and control conditions. Corrosion rates were very low (0.05mm/year) under the buried environment.

The table below describes the material loss in steel from each set of test coupons. It is significant to note that most corrosion tests are completed in six months; these tests were completed over nine months. Reviewing data in the table documents corrosion on the treated coupons is both less than the control, and also shows signs of slowing significantly over time. Corrosion on the control coupons is accelerating over time. With five years between renewal surveys this further emphases the advantages VOS brings to a vessel.

| **Tank Identification** | **Environment** | **Average Weight Loss (gms)** | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | **Number of days** | | | | | | |
| | | **32** | **60** | **89** | **123** | **158** | **180** | **270** |
| **Tank 1, De-oxygenated** | Wheel | 2.74 | 4.27 | 7.32 | 11.09 | 12.17 | 13.62 | 17.27 |
| | Submerged | 2.01 | 3.25 | 6.91 | 8.71 | 10.01 | 11.74 | 12.33 |
| | Humid | 1.45 | 1.82 | 1.99 | 3.41 | 4.64 | 5.22 | 4.86 |
| | Buried | 0.69 | 1.24 | 2.71 | 1.30 | 1.18 | 3.16 | 1.90 |
| **Tank 2, Control** | Wheel | 4.47 | 7.49 | 9.22 | 11.55 | 13.76 | 15.85 | 27.67 |
| | Submerged | 3.83 | 5.07 | 4.74 | 4.97 | 6.24 | 6.34 | 11.44 |
| | Humid | 6.64 | 11.47 | 13.67 | 15.26 | 16.01 | 21.16 | 27.15 |
| | Buried | 0.79 | 0.92 | 1.31 | 0.51 | 0.58 | 1.15 | 2.72 |

**Treated, left and Control, right after 270 days in the Humid Zone**






**The corrosion testing clearly show the advantages for a vessel using a VOS system**

## Coating System Test Results

From BMT's initial report, there was no significant difference in the performance of coating systems under de-oxygenated and control conditions. There was no creepage in modified epoxy coatings under both the conditions (de-oxygenated and control). The performance of the coal tar epoxy coatings was slightly better under de-oxygenated conditions as compared to control conditions.

The pictures below are from these tests. The coupons have been scored in a standard uniform way to represent physical damage to the coating, common in ballast tank they. Though not statistically quantified by BMT the pictures indicate improved performance of treated, Tank 1, over control Tank 2.


N.E.I. did not expect after only nine months the coating results would be as clear as the corrosion results. However, the apparently marginal improvement of treated over control prompted N.E.I. to complete further testing. The full reports are available as appendices E & F.

### The conclusions of the additional testing included:

*"The pull-off strength of epoxy coating at location B closer to the scribed surface is similar to the average pull-off strength at the other two locations, A and C, away from the scribe location on the same face implying the exposure of the scribed location under de-oxygenated environment did not lead to the deterioration of the coatings strength."*

## CONCLUSIONS FROM TESTING VOS

VOS passed each of the tests it was subject to. The tests proved VOS is not just an effective treatment system but a system which can be an effective Ballast Water Management System. A BWMS has to be installed and work effectively aboard an operating vessel. VOS has been installed aboard; tankers, bulkers and a container ship, systems with Total Rated Capacities of $250m^3$/hr to $6,350m^3$/hr, vessels from 7,700 DWT to 320,000 DWT.

These installations combined with the successful results of the testing described here prove VOS is qualified to be used as a BWMS on commercial vessels trading in any type of water anywhere in the world.

The experience and installations prove VOS is qualified to be used on all type of vessels, at all practical flow rates and any location on the planet. VOS allows a vessel to operate without a significant impact to operations, without using filters or Active Substances. Perhaps more importantly VOS brings no danger of discharging an Active Substance to the environment.

### Biological Testing

Testing both land-based and shipboard in; fresh, 0 PSU, brackish and salt water with biological abundances in excess of guidelines all proved VOS exceeds the USCG-Phase 1 and IMO-D2 ballast discharge standards.

## Zooplankton or organisms >50 µm:

- The VOS system routinely killed all organisms in this range and always returned IMO D-2/USCG compliant results. This was true for both natural water tests and seeded trials.

## Phytoplankton or organisms from 10 to 50 µm:

- The multiple methods used to count cells always returned counts of "0.00" in the treated water after 96 hours (in order to meet the hold time requirement of the IMO). This was documented after regrowth of healthy looking cells from each sample returned zero viable cells post treatment. **As a note:** The most advanced techniques for assessing phytoplankton counts and viability were used. The best available methods indicate a hold-time of 48-72 hours for full VOS treatment of phytoplankton.

## Bacteria:

- Millions of bacteria were counted in each ml of treated and untreated water. The numbers in the treated samples revealed very significant bacterial kill rates. The significantly reduced numbers in all treated compared to control samples indicate that bacteria are not blooming on the nutrients of other organisms killed by the VOS treatment. Counts for both *E. coli* and *Enterococci* quickly met the D-2 standard in both seeded trials and the natural water trials. Within a matter of hours after treatment.

## Environmental Testing:

As required by 46 CFR 160.060-30, all VOS control and monitoring components were subject to extensive environmental testing. All components passed the testing without incident, at the Retlif laboratory in New York.

## Corrosion and Coating Testing:

Long term independent testing proved significant reductions in corrosion of bare steel when VOS is used. This was consistent throughout the ballast tank but most dramatic in the Humid Zone of the tank where an 80% reduction was seen. Corrosion Testing Reports are included as Appendices E & F below.

Coating tests proved VOS has no deleterious effects where coatings are undamaged. The tests also prove that VOS significantly slows deterioration where coatings are damaged.

### VOS Tested to the USCG-Phase 1 and IMO-D2 Ballast Water Discharge Standards

- VOS increases safety for the crew and has no negative impact on the environment
- The major VOS components have been used aboard vessels for decades, and therefore all well understood by Class, SOLAS and crews
- VOS provides proven corrosion protection to a vessel, and therefore safety and financial benefits
- VOS is automated and simple-minimal impact to operations
- VOS ensures 100% effective treatment of ballast water regardless of conditions and water type
- VOS has been thoroughly tested by MERC and other agencies in salt water, fresh water and brackish water. It has proven to maintain full efficacy regardless of water condition or type
- VOS results and installation procedures have been thoroughly reviewed by multiple Class societies and 3rd party laboratories

# Modifications Since Testing

VOS is a physical treatment system, relying on the difference in oxygen concentration between fresh air and the generated stripping gas.

- Stripping Gas is produced by the VOS Stripping Gas Generator.
- A Venturi Injector introduces the gas to the ballast Water.

The fundamentals of VOS have remained constant since the very first bench trials in 2002. VOS has been patented and remains constant in its fundamental treatment design.

## VOS Development

While the fundamentals of VOS have not changed, some of the mechanical and monitoring components have been refined and updated. VOS has benefitted from significant developments in the design and power of PLC controllers, particularly those available from the Intelligent Platforms group at General Electric (GE).

- The most significant mechanical update has been the design of the SGG. The operating requirements of gas quality and volume have not changed, but the layout has been improved to help with maintenance and increase installation flexibility
- New GE PLC Controllers recently expanded processing, orders better than the first VOS systems. This has allowed more parameters to be monitored simultaneously, though again the fundamental layout and control requirements have not changed.
- The data storage capability of the new components is also orders of magnitude better than initial designs. VOS can now save many years of data internally, and make it available via; the control screen, a print out or a USB port.
- Advances in materials allow N.E.I. to supply VOS with composite instead of cast iron butterfly valves. These units are stronger, lighter and will not corrode, all reducing the impact VOS brings to a vessel both financially and operational. No impact to performance, but a significant materials improvement.
- Development will continue; next month a new Magnetic Vent Valve will be tested with DNV, and the very first VOS-CS (Combined System) will be delivered and installed. The Combined System allows a tanker to use the SGG to both treat ballast water and inert cargo tanks simultaneously. This allows a vessel to complete two major functions with one piece of equipment. In addition, cargo inerting is considered a “Critical” function by class societies and SOLAS. The VOS system is capable passing these much more stringent requirements for quality and safety.

These developments are shared here as an indication of the commitment of N.E.I. and it license partners to improve VOS. All of the improvements are in the categories of; 1) installation flexibility 2) utility and 3) ease of operation/maintenance. VOS has not fundamentally changed as a treatment system, because the physical process used is a constant understood by science for over 200 years.

# VOS and AMS

Through years of testing at U.S. approved Independent Labs such as MERC, Retlif, U.S. Naval Research Center and others, the VOS Ballast Water Management System has proven that it meets and exceeds the criteria of an AMS. N.E.I. is requesting AMS status for VOS systems, based on the data presented in this document, the cover letter and the included appendices. N.E.I. is requesting the following criteria be used for USCG review, and if granted to include the following descriptions and restrictions in the acceptance letter:

- Ballast Water Management Systems supplied by, or under license from, N.E.I. Treatment Systems, LLC
- For Type and Model Designations; VOS-250, VOS-500, VOS-1000, VOS-2000, VOS-3000, VOS-4000, VOS–5000 and VOS-6000
- All water types including salt, fresh and brackish as complete testing has been completed for all
- All levels of turbidity (transmittance level) as VOS is not impacted by water clarity in any way
- All temperature ranges as VOS is not impacted by water temperature
- Treatment Rated Capacities ranging from: 100$m^3$/hr. thru 6,800 $m^3$/hr. per unit (multiple units can be installed on a vessel if more than 6,800 $m^3$/hr. is necessary).
- VOS SGG must be installed in machine space, all other components are Intrinsically Safe
- When used as both a cargo inerting AND Ballast Water Treatment System the VOS SGG must meet Class and SOLAS requirements for Inert Gas Generators as well Ballast Water Treatment

# Backup Data for VOS AMS Submission

## Descriptions

**Appendix-A:** This document provides the Flag certificates (Type Approval) for the five countries who have reviewed all VOS data and issued their approvals with no restrictions. Also included are the N.E.I. STEP acceptance letter from the USCG and the California Lands Commission letter approving the discharge of VOS treated water, under the STEP program. This appendix also includes a comprehensive review from ABS, which was and continues to be used as the foundation for all N.E.I. Type Approval Submissions.

**Appendix-B:** "*Evaluations of a Ballast Water Treatment to stop invasive species and tank corrosion*" by Dr. Mario Tamburri and Dr. Gregory Ruiz. This document is the summary of all VOS testing and results, produced by Dr. Mario Tamburri of the Maritime Environmental Resource Center, and Gregory Ruiz of the Smithsonian Environmental Research Center. The paper summarizes the results for VOS lab-scale testing, land-based testing (full size unit), shipboard testing (production unit) and corrosion testing.

**Appendix-C:** "*Quantitative shipboard evaluations of Venturi Oxygen Stripping as a ballast water treatment*" by Dr. Mario Tamburri of MERC. This paper is a more in-depth analysis of the three shipboard evaluations completed by N.E.I. onboard the actively trading vessel; *Pat Cantrell*.

**Appendix-D:** Retlif Laboratory report covering all Environmental testing of the NEI VOS system. Report includes all test descriptions and telemetry associated with each test.

**Appendix-E & F:** Summary papers completed by BMT Fleet Technologies. These documents describe the testing and results of the VOS system, and a method to prevent the corrosion of structure and coatings in ballast tanks. These nine-month studies were completed by a third party, and peer reviewed. Dr. Sanjay Tiku completed the studies and documented the results in these papers, proving VOS reduces corrosion and therefore has a positive financial and safety impact on the vessel.

**Appendix-G:** Complete ABS review of the system and installation for the SAMCO Company. This is the largest system in the world, to our knowledge, operating at 6,350 $m^3$/hr., onboard a VLCC (this VOS system is capable of operating at up to 6,800 $m^3$/hr). There are a total of four systems now installed and commissioned for SAMCO, using this ABS review as a template.

**Appendix-H & I:** Complete gas chromatography analysis of gas generated by the Stripping Gas Generator (H) and cooling water discharged from the land-based VOS test system (I).

**Appendix-J:** Raw data from all VOS testing. The data represent lab-scale, land-based (production size unit) and shipboard trials (production unit).

**Appendix-K:** Discharge monitoring of VOS treated water. Waters receiving VOS treated water as discharge was closely monitored during lab based, land based production and ship board production testing. The studies prove a complete absence of impact to waters surrounding a vessel. Also included is the Los Angeles Coastal Watershed Plan. VOS discharge conforms to this plan's requirements, which are some of the most stringent in the U.S.

Include here also is the *Wye lab Acute and Chronic Toxicity testing*. Completed in 2009 after G8 was changed at MEPC 57. These ecotoxicalogical tests proved VOS discharge is not toxic on an acute or chronic basis. Testing was completed on a "Whole Effluent Test" (WET) basis – without dilution.